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INVESTIGATION OF USE OF SPACE DATA IN WATERSHED HYDROLOGY

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Prepared for

GODDARD SPACE FLIGHT CENTER

Greenbelt, Maryland 20771

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16. Abstracts Digital data from the ERTS multispectral scanner was used to investigate the feasibility of identifying differences in watershed runoff capability with space-borne sensors. Linear combinations of the two visible light bands and a combination of the four visible and near infrared bands were related to a coefficient used in the Soil Conservation Service storm runoff equation. Good relationships were found in two scenes, both with dry surface conditions, over the same watersheds. The relationships defined by both combinations of digital data were tested on an independent set of 10 watersheds and on an additional 22 subwatersheds. Coefficients predicted with the ERTS data proved better than coefficients developed with conventional methods.

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PREFACE

Objective:

1. To determine whether ERTS data can be used to characterize parameters affecting watershed runoff.

2. To compare the performance of hydrologic models when routine manually determined parameters are used versus when ERTS derived parameters are used.

Scope:

The study was based on the hydrologic data pertaining to 20 highly instrumented watersheds located in central Oklahoma. Data from one group of 10 watersheds was related to linear combinations of mean digital MSS data to develop a prediction scheme for watershed runoff coefficients. Two storm runoff equations were fitted to the watershed data to arrive at measured coefficients that represented watershed surface conditions. The SCS storm runoff equation was used in this study to illustrate that with dry surface conditions the coefficient commonly called the runoff curve number can be related to ERTS-MSS digital data. Predictions based on the relationship found in two ERTS scenes were tested on the remaining 10 watersheds.

Conclusions:

Predictions were significantly improved over the runoff curve numbers calculated by conventional means, and major improvement in estimates of flow into flood control works is possible. The use of the technique produces objective estimates of watershed runoff that can be repeated. This study was not extensive enough to determine if dense vegetation on watershed surfaces will limit the application of the technique.

Summary of Recommendations:

A follow-on study to test the prediction technique on heavily vegetated watersheds and determine the extent of the regions where the technique can be used.

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LIST OF ABBREVIATIONS AND SYMBOLS

USDA	United States Department of Agriculture
ARS	Agricultural Research Service
SCS	Soil Conservation Service
USGS	United States Geological Survey
MSS	Multispectral Scanner
ERTS	Earth Resources Technology Satellite
API	Antecedent Precipitation Index
CN	Curve Number, a coefficient for the SCS storm runoff equation, No. 1.
C	Coefficient for equation No. 2.
P	Weighted storm precipitation
Q	Watershed runoff
S	Storage in surface soils
μ_x	Mean of digital values for band x.

1.0 Introduction

Engineering works for the control of flood waters have been built throughout several centuries, but never at the pace that will be required to protect life and food production capacity for our fast growing world population. Safe and economical design of flood control structures such as dams, diversion dikes, and conveyance channels require reliable estimates of flood flows that can be expected from the watershed areas above the structure. To gain some understanding of water supplies and watershed runoff, many hydrologic measurements; river stages, flow volumes, rainfall and snowfall, and topographic measurements have been accumulated in recent times. The hydrologic measurements available today pertain primarily to large river basins and, in some instances, drainage areas of smaller watersheds in regions that have historically high density populations.

Long periods of record, 30 years or more, are desirable to establish the rainfall-runoff relations that can be expected in both high and low rainfall seasons. Instrumentation and manpower to gather and compile adequate hydrologic records are expensive and time consuming, therefore, watersheds selected for monitoring are usually those where the need for data is most critical. The more developed countries of Europe and North America have never had resources available to accumulate watershed runoff data to meet future needs, while underdeveloped nations have even less data to use in the design of flood control structures.

The United States Geologic Survey (USGS) has been the primary agency responsible for gathering watershed runoff information in this country. Their efforts prior to the last decade were directed toward data collection for large basins where the Department of Interior or the U. S. Army Corps of Engineers would be responsible for designing flood control works. Runoff from tributary watersheds has been recorded by the USGS on only a small percentage of the tributary watersheds as funds would permit.

The United States Department of Agriculture (USDA) on the other hand, has monitored rainfall and runoff from many small drainage areas. The small drainage areas usually consisted of a so-called unit source area having uniform soil and cover. Their interest was in the drainage area rainfall-runoff relations needed to design small detention and control structures for farmers either to control erosion or provide water for livestock. The United States therefore has rather extensive records of runoff from most large river basins and numerous small unit source areas. Runoff records for agricultural watersheds with 1.0 to 500 square kilometers in drainage area are generally not available.

Runoff and flood flows from small agricultural watersheds have, in recent years, become an important concern of the agricultural and small town property owners. The control of floods by construction of numerous small detention structures on branches of a tributary watershed has become an accepted practice. At the same time, runoff from small watersheds has become important as a water supply for municipalities.

Reliable projections of the quantity and rate of runoff from the surface of the land into rivers and streams are difficult to obtain for ungaged watersheds. However, this information is needed in the design of any structure located in the vicinity of a water course; for example, the storage capacity of municipal water supplies and flood detention structures. When projections of runoff are questionable, the storage capacity of such structures is quite often overdesigned. Overdesign not only increases construction costs, but may also lead to significant reduction in the flushing action needed to maintain good water quality in structures where inflow is initially saline and evaporation rates are high.

Examples of overdesign are frequently observed throughout the Great Plains. In the central reach of the Washita River basin, a water supply reservoir for the city of Chickasha was completed in 1958. The history of runoff into this structure for the past 15 years shows that the anticipated runoff exceeded the observed by several times. As a result of the overdesign and other related problems, the salinity of the stored water has increased sufficiently to preclude use as a municipal water supply and even sometimes as an irrigation source.

In an adjacent watershed, Sugar Creek, a study of the response of a large number of flood detention structures to a large storm on September 19-20, 1965 shows that the inflow was only about one-half that expected.

The quantities and rates of runoff that are used to design structures such as these are estimated from various types of watershed runoff models. These models are mathematical equations, generally of an empirical form, based on the drainage area, topography, soil and cover of the subject watershed. Usually, parameters of these models represent drainage area and surface conditions prevailing at the time of a rainfall event. The integrated influence of these characteristics combined with measurable climatological parameters (rainfall, antecedent moisture, rainfall intensity, etc.) can produce reasonable estimates of storm runoff. Efforts have been made to quantify the integrated influence of soils, cover and surface roughness. However, at the present time, no objective means exists for estimating this influence. Present methods for estimating this influence are tedious, expensive and subject to judgment of the hydrologist.

The problem of subjectivity associated with present methods that are used to derive coefficients of runoff equations may be circumvented by applying digitized data obtained from ERTS. Even though hydrologic analysis based on photographic data obtained from ERTS suffers from the same subjectivity as do the existing methods, data obtained from the multispectral scanner, MSS, on board the satellite can provide digital data that can be incorporated into mathematical equations. This type data is less subjectively biased than are the other types of data.

The ERTS multispectral data is also superior to aerial digital data collected prior to ERTS because the relatively constant sun angle within an ERTS frame, caused by the satellite's sun synchronous orbit, eliminates many of the problems in comparing the spectral reflectance from watershed surfaces. The ERTS data has additional advantages in that there is sufficient spatial resolution to allow the identification of watersheds as small as 10 hectares, and yet the number of data points depicting a large watershed are reduced to a manageable number.

This study was conducted to investigate the possibility of using ERTS-MSS digital data to define the coefficients for watershed runoff models used on small ungaged watersheds and thus provide economical and timely data for planning and design of flood detention structures.

Estimates of runoff from small watersheds are usually made either by use of a simple empirical runoff model or by use of the modern complex watershed models. The empirical watershed models are widely used by practicing hydrologists. Numerous brief models have been developed in the last century, however, one in particular, developed by the USDA Soil Conservation Service (SCS) is most commonly used in the United States (Mockus, et al., 1971).

The SCS equation:

$$Q = \frac{(P - .2S)^2}{P = .8S} \tag{1}$$

where $S = \frac{1000}{CN} - 10$

Q = storm runoff (cm/2.54)

P = weighted storm rainfall (cm/2.54)

S = storage in the watershed surface (cm/2.54)

CN = function of soil, cover, antecedent moisture (dimensionless)

All of the many empirical runoff equations represent the influence of near-surface storage by use of one or more coefficients. In this equation, the coefficient, CN, commonly called the curve number is a function of the surface characteristics of the watershed at the time a storm event begins. No attempt is made to describe the dynamic changes in storage through the storm period due to changes in infiltration rate in the soil, depletion of available storage in the vegetation, or depletion of storage in the soil.

The SCS runoff equation was developed from data collected on small plots located in several regions with a variety of soils and cover. Tables were developed from these data to define the influence of soil type, vegetative cover, and antecedent moisture conditions. To apply the equation, each unit of area with a single soil type and single cover must be assigned its own curve number. The areas and curve numbers are tabulated for an entire watershed drainage area and the curve numbers are weighted by area to determine an average curve number for the watershed. Thus, the computation of the watershed curve number is not only dependent on the judgment and experience of the hydrologist, but also is time consuming and subject to computational errors.

The goal of this study has been directed toward development of a technique where the coefficient CN for the SCS runoff equation can be determined objectively from ERTS data.

2.0 Approach:

The problem was approached by first assuming that differences in the soil-cover complex over a watershed area would be detectable by differences in reflectance of visible and/or near infrared light. The reflectance in each band of light available from the digital data of the ERTS multispectral scanner could then be averaged over a watershed drainage area to provide a single value for comparison to measured watershed runoff coefficients.

Twenty watersheds with extensive measurements were selected to represent the widest range of rainfall-runoff response experienced in central Oklahoma. The watersheds were then to be divided into two comparable groups of 10, each group having as near as possible, the same range of sizes and the same range of runoff coefficients. Group I watersheds would then be used to distinguish and develop a relationship between the coefficients of a runoff equation and MSS data. Group II watersheds were set aside for verification.

To accomplish this, storm rainfall, storm runoff, rainfall intensity, and antecedent rainfall would be calculated and compiled for the available period of record on each of the 20 watersheds. These data would provide the basis for evaluating the actual rainfall-runoff response of each watershed and determine the measured curve number (CN) for each watershed. These data would provide the basis for grouping the watersheds and also be sufficient to evaluate other simple empirical runoff equations by fitting the data to the equations and optimizing the coefficients. Existing computer programs for optimization were available for processing these data.

Processing of the MSS digital data was planned in several steps. First, to elininate the costs of handling large volumes of digital data, 70 mm black and white photographs of MSS-5 data were requested to screen the available supply and limit the study to cloud-free scenes representing all seasons of a year. Secondly, computer programs would be developed to identify, extract, and isolate the digital data that represented each watershed drainage area. A technique would be developed where watershed boundaries could be mapped on an overlay for a display system allowing selection of coordinates for a series of points that would define the boundaries of the location of data on the digital tape. Computer programs could then be written to excerpt the pertinent data, store it in separate files and compute the mean and standard deviation of each band over the surface of the individual watershed.

It was then proposed that the linear combinations of mean spectral response from the four bands would be examined by multivariate analysis techniques and simple curve-fitting techniques to find the best relation between the MSS data and watershed runoff coefficients. Only data from Group I watersheds would be used to develop the relations. If an acceptable relation existed, it was then to be used as a prediction scheme on the Group II watersheds. Both predicted coefficients and coefficients developed by the conventional SCS procedure would be compared to measured coefficients to determine if the remote sensing technique could determine coefficients as well or better than the conventional method.

3.0 Ground Truth and Data Processing

3.1 Basic Data

Ground truth for this study consisted of recorded hydrologic data collected by the Agricultural Research Service (ARS) from the 1961 through 1972 time period. The 20 watersheds used are located in Grady and Caddo Counties in central Oklahoma. The watersheds generally represent small tributary watersheds of the Southern Great Plains area. Mean annual rainfall in the area is 78 cm.

Two hundred and fifty-six storm events were selected from the records of the 20 watersheds. Storm events were selected on a basis of weighted mean storm rainfall greater than 3 cm. and measured runoff greater than .03 cm. The number of acceptable events ranged from 9 to 21 events per watershed.

3.2 Data Compilation

Data compiled for each storm event used included weighted mean rainfall, runoff, antecedent rainfall index (30-day, decayed), antecedent rainfall index (5-day sum), and maximum hourly intensity. Drainage area above farm ponds varied from 0 to 40 percent of the total drainage area within each watershed. Farm ponds would modify runoff to a different extent on each watershed, therefore runoff was adjusted to an estimate of the contributing area using records of farm pond storage. The 30-day antecedent rainfall index (Linsley, et al., 1949) was computed by depleting the residual rainfall index daily by a seasonally varying constant. The constants used were derived from an inverse mean daily temperature.

Antecedent rainfall index calculated in this manner is usually more realistic than simple summation of prior rainfall over some period of time. An antecedent precipitation index was calculated for the entire study area and values were selected for each day an ERTS scene was taken. Antecedent precipitation index values for the day of each scene used in this study are listed in table 1. Summation of rainfall for the 5-day period prior to each storm was compiled for these storms since the SCS procedure uses this index to account for prior rainfall.

Table 1. Antecedent Precipitation Index for Scene Dates

Scene Number	Date	30-Day API (cm/2.54)
1058	09-19-72	.028
1094	10-25-72	2.27
1184	01-23-73	1.94
1256	04-05-73	1.19
1274	04-23-73	.928
1400	08-27-73	.0180
1508	12-13-73	1.063

3.3 Curve Numbers Calculated

The rainfall and runoff values were used in the SCS runoff equation (Equation 1) to calculate actual curve numbers for each storm event. It is apparent from a study of these events that conversion from one class to another in the SCS routine is not appropriate to storms in this study area unless a large number of storms have occurred in each antecedent condition class. A large majority of the events were in the Class I category of antecedent precipitation index used by SCS. Therefore, only Class I storms were used to derive mean curve numbers for watersheds in this study.

3.4 Curve Numbers by Conventional SCS Method

The Soil Conservation Service had previously determined conventional runoff curve numbers for 12 of the watersheds used in this study. These were furnished to ARS along with soils maps and photo mosaics of each watershed for computation of curve numbers for the remaining 8 watersheds by the conventional SCS method. Land use was interpreted from color and color IR photographs taken on the ERTS aircraft support flights. Singular soils - land use classes were identified, assigned a curve number and the area of each class measured. Weighted mean curve numbers were then calculated from these data.

A listing of the curve numbers calculated from measurements and those calculated by conventional SCS techniques can be found in table 2.

3.5 A Second Runoff Equation

Attempts were made to fit another runoff equation to the data using precipitation, 30-day antecedent precipitation, and maximum hourly intensity as variables. Very poor results were obtained after trying several linear combinations of the variables. Ultimately the intensity was deleted and runoff was fitted to rainfall alone, then deviations in predicted runoff from measured runoff were fitted to the 30-day decayed

Table 2. Summary of Watershed Data*

Watershed Number	Drainage Area (km^2)	Percent DA above Ponds	Measured CN (Eq.1)	Conventional CN (Eq.1)	Constant C (Eq.2)
		Group I			
206	.110	0.0	53.6	61	.034
207	.0777	0.0	75.8	86	.122
111	67.3	26.4	60.9	71	.038
141	190.	20.0	58.0	74	.023
512	91.2	31.4	67.2	74	.050
513	49.7	34.4	65.7	74	.054
5141	16.4	28.2	61.5	74	.041
5146	3.08	31.1	63.8	73	.068
522	539.	19.5	57.1	73	.031
612	2.28	20.7	66.7	74	.057
		Group II			
205	.0959	0.0	54.4	61	.039
208	.0749	0.0	77.4	83	.147
121	534.	21.2	58.6	78	.023
311	65.5	40.7	69.6	77	.078
511	154.	34.4	69.4	75	.082
5142	1.39	45.4	59.4	76	.027
5143	1.97	33.7	56.3	68	.021
5144	5.90	38.4	62.8	76	.066
611	19.6	31.3	70.2	77	.065
621	86.2	20.6	67.4	77	.057

*All values other than drainage area are dimensionless.

antecedent precipitation thus leading to the exponential values to relate runoff to precipitation and antecedent precipitation. These exponents were derived using all 256 storm runoff events. The resulting equation was in the following form:

$$Q = C\ P^{2.15}\ API^{.278} \qquad (2)$$

in which Q = watershed storm runoff (cm/2.54)

C = a dimensionless coefficient representing differences in watershed conditions

P = weighted mean storm rainfall (cm/2.54)

API = 30-day decayed antecedent rainfall index derived using inverse temperature curves to adjust for seasonal variations (cm/2.54)

The exponents were then fixed in Equation 2 and a mean coefficient fitted for each watershed (Table 2). The coefficients and exponents accepted for this simple equation predict runoff that has a multiple correlation with the measured runoff of .7220, whereas the SCS equation using curve numbers accepted for this study produce a multiple correlation of .7112 when compared to the measured runoff. This indicates the two equations used are of comparable quality for predicting storm runoff in this region. Use of only one or two storm parameters cannot be expected to produce better results than this.

3.6 Map Requirements

Maps were obtained for each of the watershed areas. The coordinates of a series of points defining the watershed boundaries and major stream channels were selected on a chart reader to produce a card deck for each watershed. These data decks were stored on disk files and used as control for a plotter program to produce overlay maps. Overlays were then plotted to match the scale of ERTS data displayed on a television screen or to match a conventional grey scale computer printout. Location of major water bodies in or near the watersheds were also mapped to aid in positioning the boundary overlay.

4.0 ERTS Data Processing

4.1 Data Screening

Microfilm of the ERTS scenes and the data search system available at Goddard Space Flight Center were used for preliminary screening to select relatively cloud-free scenes over the study area. Nine-inch photographs of the data were then used for a second look before bulk digital tapes of the MSS data were ordered.

4.2 Digital Data Selected

Multispectral digital data for the watershed areas were obtained from the ERTS scanner for seven scenes that covered the study area. Each scene represented major changes in soil moisture and vegetative conditions. The first scene, 1058, dated September 19, 1972, shows a dry dormant condition with almost no ground cover. The second scene, 1094, dated October 25, 1972, provides data with essentially the same ground cover, but extremely wet conditions. The third scene, dated January 23, 1973, showed minor growth in winter wheat fields and wet conditions. The scenes, 1256, dated April 5, 1973 and 1274, April 23, 1973, showed substantial ground cover for crops, pastures, and timber. One of the growing season scenes was extremely wet and one moderately dry. The last two scenes, dated August 27, 1973 and December 13, 1973 show extremely heavy vegetative growth on cropland for the fall and winter seasons. Table 1 lists the calculated 30-day antecedent precipitation index associated with each scene used. Reflectance in the near infrared, band 7, was relatively high in the grassland areas on the fall scene, indicating more growing vegetation than on the scene from the previous fall.

4.3 Data Processing Approach

The MSS data from ERTS were obtained in the form of sequential and adjoining tapes that were laced together with the aid of a computer program (MERGE, Appendix) forming a single file for each watershed area. Due to the nature of the problem, it is very important to keep the relative position of the data points correct and to be able to accurately define its location within a watershed. Without this, coordination of ground truth and spectral response would be impossible. Since the methods used to display the MSS digital data present an image enlarged in the cross-track axis, the maps developed as part of the ground truth data were also enlarged in the cross-track axis before they were used to locate watershed boundaries.

Data sets for the larger watersheds were obtained by displaying the entire ERTS frame for the area of interest on a television display. The portion representing the watershed was isolated using the distorted maps and a computer program (OKLAH, Appendix). The computer program represents the watershed boundary by a series of adjacent parallelograms. About 20 parallelograms seem to be enough to adequately define the watershed boundaries (Fig. 1). This program stores the watershed data on a secondary tape in a rectangular file placing zero values in all data points outside the watershed boundary. The ERTS data format is retained on the secondary

Figure 1. Display of MSS 5 data for Watershed 512

tape so the data pertaining to the watershed areas can be displayed on the screen for visual verification that the data selected covers the entire watershed drainage area.

Data sets for the small watersheds were more easily obtained by displaying the ERTS data on computer printout and overlaying it with distorted maps. In both procedures, ponds and channels aid significantly in locating specific points that assure proper selection of the watershed boundary points on the MSS data tapes. In some data sets, stream channels are difficult to locate in grassland areas; a study of the ERTS data showed that MSS band 5 resolved the stream channels and ponds sufficiently well to position the overlay. However, during the growing season, (MSS band 4 + MSS band 5)/MSS band 6 enhanced the resolution of the stream channels. Although cumbersome, the system described for small watersheds will work to locate larger watersheds if a display system is not available. Ratioing bands 5 and 7 also helped to enhance some scenes where single bands offer little contrast.

A simple computer program (Mean 4, Appendix) was used to calculate the mean and standard deviation of the digital values for each band from the digital values stored on the secondary tapes. Computations were made for each watershed on all scenes used in the study. These values were considered as the basic set of multispectral scanner data that would be compared to the hydrologic data. A summary of these data from the seven scenes can be found in the Appendix.

The MSS data from scene 1058 was used as a base to determine if all data points were necessary in the computation of mean values for each watershed. From each of the watersheds represented by more than 5,000 data points, 256 independent samples were selected. By calculating the means, sample size, and standard deviation of each sample, then combining adjacent pairs of samples and repeating the process, the change in the mean and standard deviation with change in sampling frequency was observed. Less than 1 percent change in the mean occurs between any sample greater than approximately 2,500 data points and the sample that includes all data points in the watershed. In an operational system it seems reduced sampling could therefore be used to cut computer costs when studying large watersheds without impairing the quality of the data.

4.4 Aircraft MSS Data

Aircraft tapes from the 24-channel MSS flown in support of this project were converted to an ERTS-type format for display on the Dicomed. The data quality seems to be erratic and unusable for a complete watershed area.

The aircraft MSS data was, however, useful for a data base in an incidental water quality study. Digital values were punched on cards for a few selected areas that contained ponds where water quality samples were collected near the time of the flight. A technique for processing of the data over water bodies was developed where distribution of the digital values in each band was defined and only the values falling within one standard deviation from the mean were used in the analysis.

5.0 Analysis

5.1 Multiple Discriminant Analysis

Since the objective of this study is to see if MSS data can be used to calculate parameters of a runoff equation, several means of relating the two data sets were used. Discriminant analysis, which can be used to study group similarity or difference and relate this to group descriptors, was used to examine the MSS data of the watersheds having extreme differences in observed runoff coefficients. Using a modified multiple discriminant analysis program (Cooley and Lohnes, 1962), good discrimination was observed between these watersheds when MSS bands 4, 5, and 7 were used in the linear discriminant function. The good discrimination was found in the dry dormant scenes, however the same band also produced the best discrimination in other scenes.

Multiple discriminant analyses considering each of the 10 developmental watersheds as an independent group showed very significant group discrimination. However, the discrimination did not appear to be related to the runoff coefficients. There was no multiple discriminant analyses program available that would evaluate two groups of 10 watersheds and maintain the ranking of the dependent variable (in this case, the runoff) within each group.

5.2 Curve Fitting

Alternatively, plots of the mean value for each band vs. the observed runoff coefficient were made. Since it appeared there might be a relationship, all possible combinations of the means were plotted. Two promising relationships were evident. The mean of MSS band 5 (μ_5) minus the mean of MSS band 4 (μ_4) is reasonably well related to the SCS runoff curve number for the watersheds in Group I. This relationship is most evident in the dry dormant scene 1058. The combination $\mu_5 + \mu_6 - (\mu_4 + 2\mu_7)$ produces a more consistent relationship when all scenes are considered. Both linear combinations of the bands were used to define prediction curves for scene 1058 (Fig. 2).

Scene 1058 occurred at a time when the 30-day antecedent precipitation index was extremely low. Data from scene 1400 acquired nearly a year later also represented extremely dry conditions. Live vegetation was more prevalent in scene 1400 than in the prior year, however, the 30-day antecedent rainfall index was .028 and .018 for scenes 1058 and 1400, respectively. Some cloud cover was found on scene 1400 and watersheds 611 and 612 could not be identified. Therefore, data from only nine watersheds in each group are available for analysis of this scene.

Figure 3 illustrates that a similar relation to the one found in scene 1058 can be described by using eight of the nine data points. The one data point that plots as an outlier belongs to watershed 111. The shift in this point is likely due to the influence of cloud cover, therefore it was not considered when locating the curves. A summary of the data used to plot the prediction curves is presented in table 3.

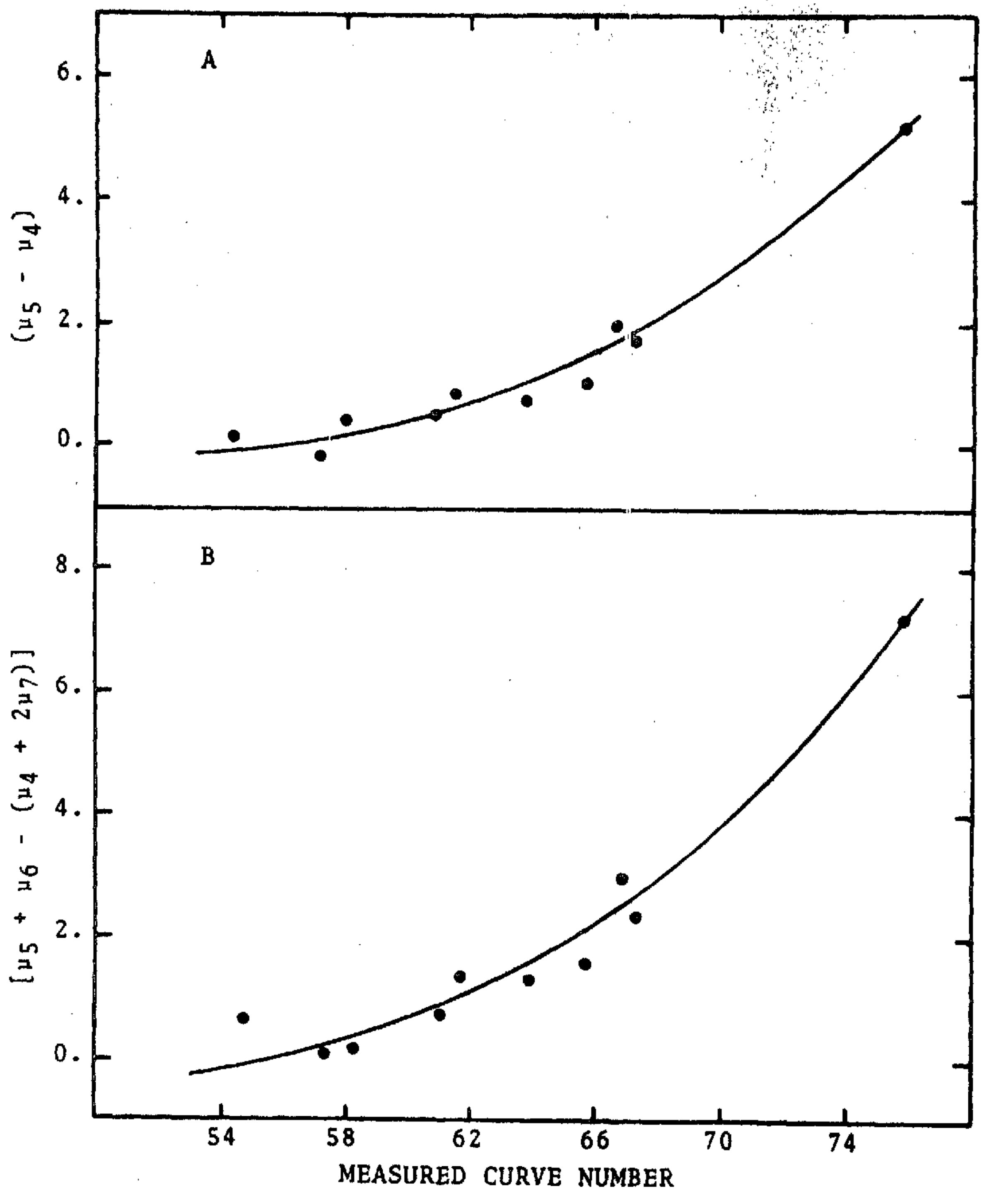

Figure 2. The relations of MSS data from Scene 1058 to measured watershed runoff curve numbers.

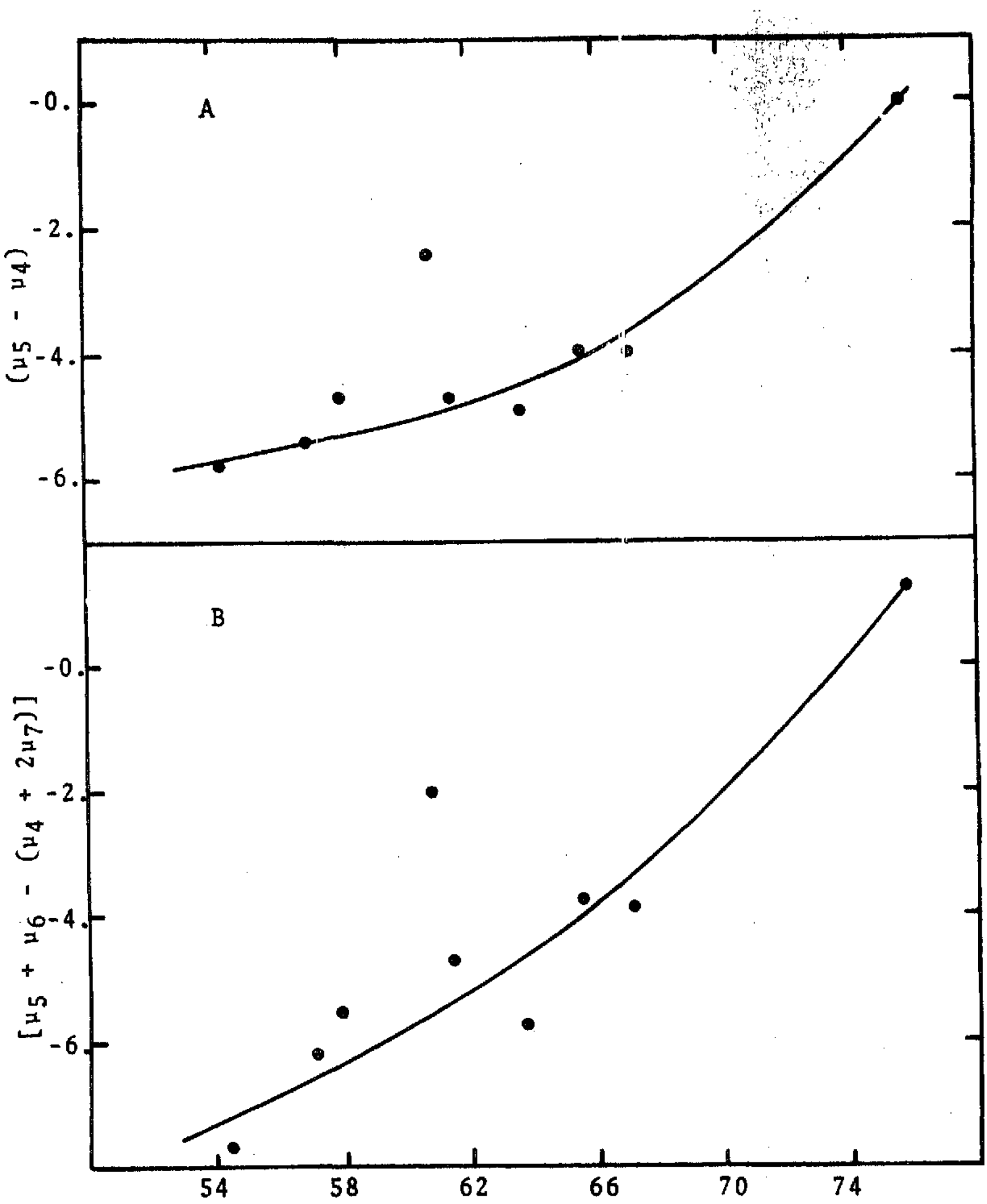

Figure 3. The relations of MSS data from Scene 1400 to measured watershed runoff curve numbers.

Table 3. Data Base for Prediction Curves - Group I

Watershed No.	205	207	111	141	512	513	5141	5146	522	612
<u>Scene 1058</u>										
$\mu_5-\mu_4$	.18	5.17	.49	.43	1.66	1.09	.81	.75	-.11	1.97
$\mu_5+\mu_6-\mu_4-2\mu_7$	.60	7.18	.74	.18	2.36	1.56	1.34	1.28	.07	2.96
Coefficient 1 (Measured CN)	54.4	75.8	60.9	58.0	67.2	65.7	61.5	63.8	57.1	66.7
Coefficient 2 (Conventional CN)	61	86	71	74	74	74	74	73	73	74
<u>Scene 1400</u>										
$\mu_5-\mu_4$	-5.80	.00	-2.36	-4.68	-3.95	-3.92	-4.72	-4.91	-5.38	--
$\mu_5+\mu_6-\mu_4-2\mu_7$	-7.62	1.32	-1.98	-5.47	-3.85	-3.75	-4.71	-5.71	-6.16	--

5.3 Prediction of Curve Numbers for Test Watersheds

Using data from scene 1058, both relationships illustrated in figure 2 were verified on the Group II watersheds (Figs. 4 and 5). In figure 4, using two bands of MSS data, predictions deviated an average of 4.13 units (absolute) from the measured values. In figure 5 when the predictions were based on using four bands of data, they deviated an average of 3.17 units (absolute) from the measured values.

Curve numbers were then predicted for the Group II watersheds by using the relationships developed from data for scene 1400. The predicted values and the conventional SCS curve numbers were plotted versus the measured curve numbers (Figs. 6 and 7). The average deviation of the predicted values from the measured curve numbers was 4.59 units (absolute) when using two bands of MSS data and 3.70 units (absolute) when using four bands of data. The average deviation of the predicted values can be compared to an average deviation of 10.72 between the conventional and measured values.

The predicted curve numbers for the Group II test watersheds are summarized in table 4. These data were used to plot figures 4, 5, 6 and 7.

Similar plotting techniques were used to examine the relation of the coefficient for equation 2. The results were comparable, however the relationships are not well defined and none seem as promising as the relationships found using equation 1.

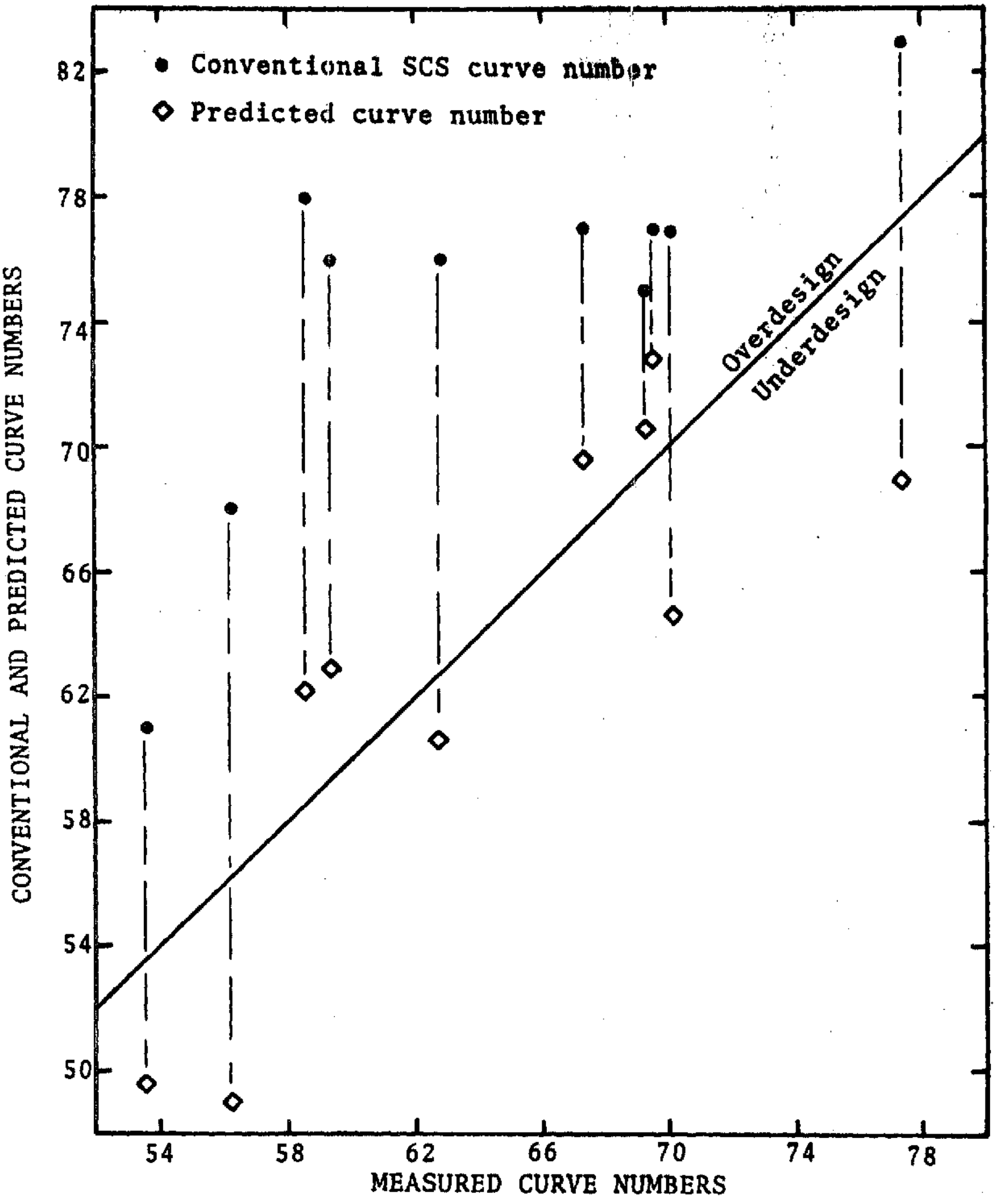

Figure 4. Comparison of conventional SCS curve numbers to curve numbers predicted with 2 bands of ERTS-MSS data (Scene 1058)

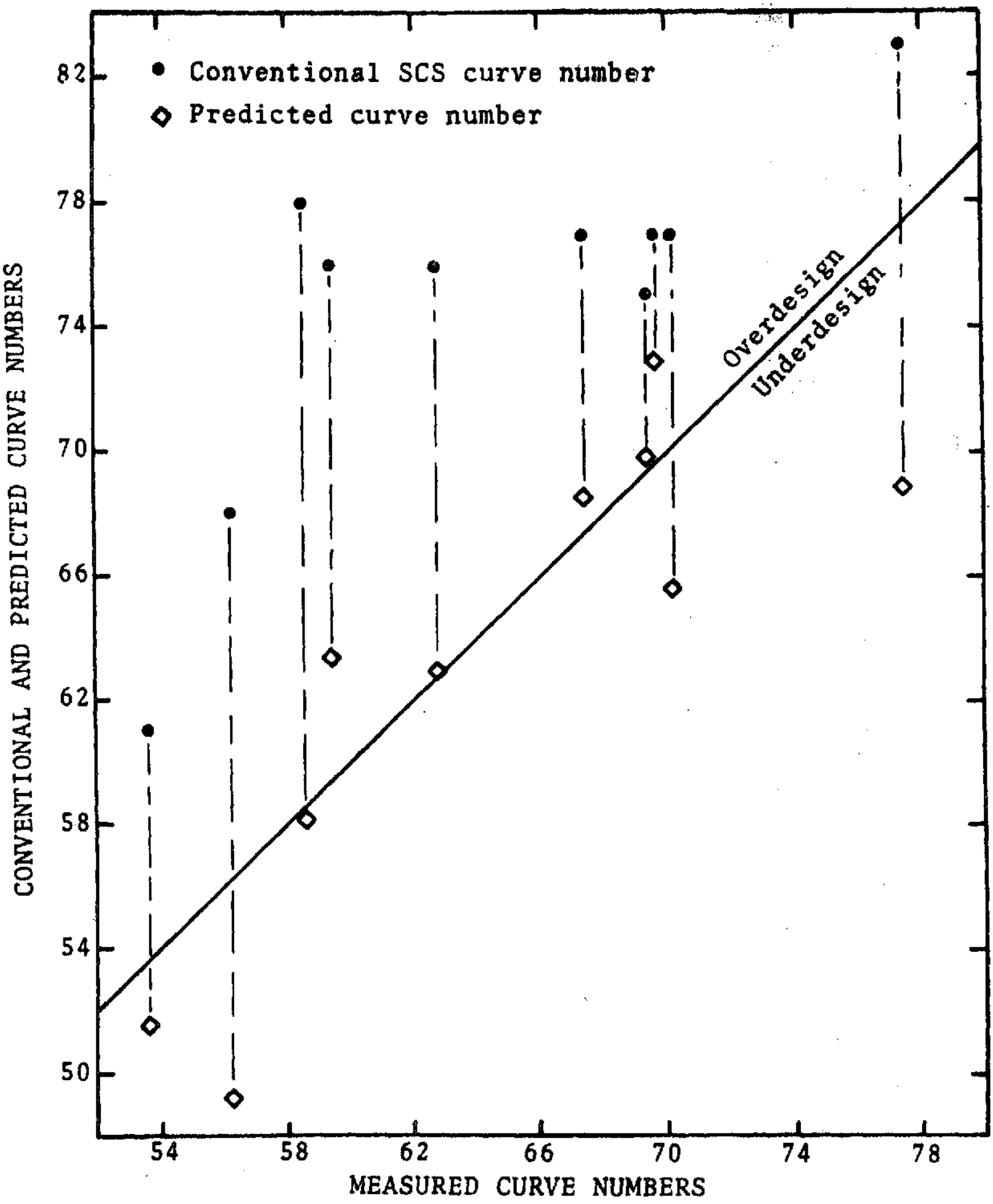

Figure 5. Comparison of conventional SCS curve numbers to curve numbers predicted with 4 bands of ERTS-MSS data (Scene 1058)

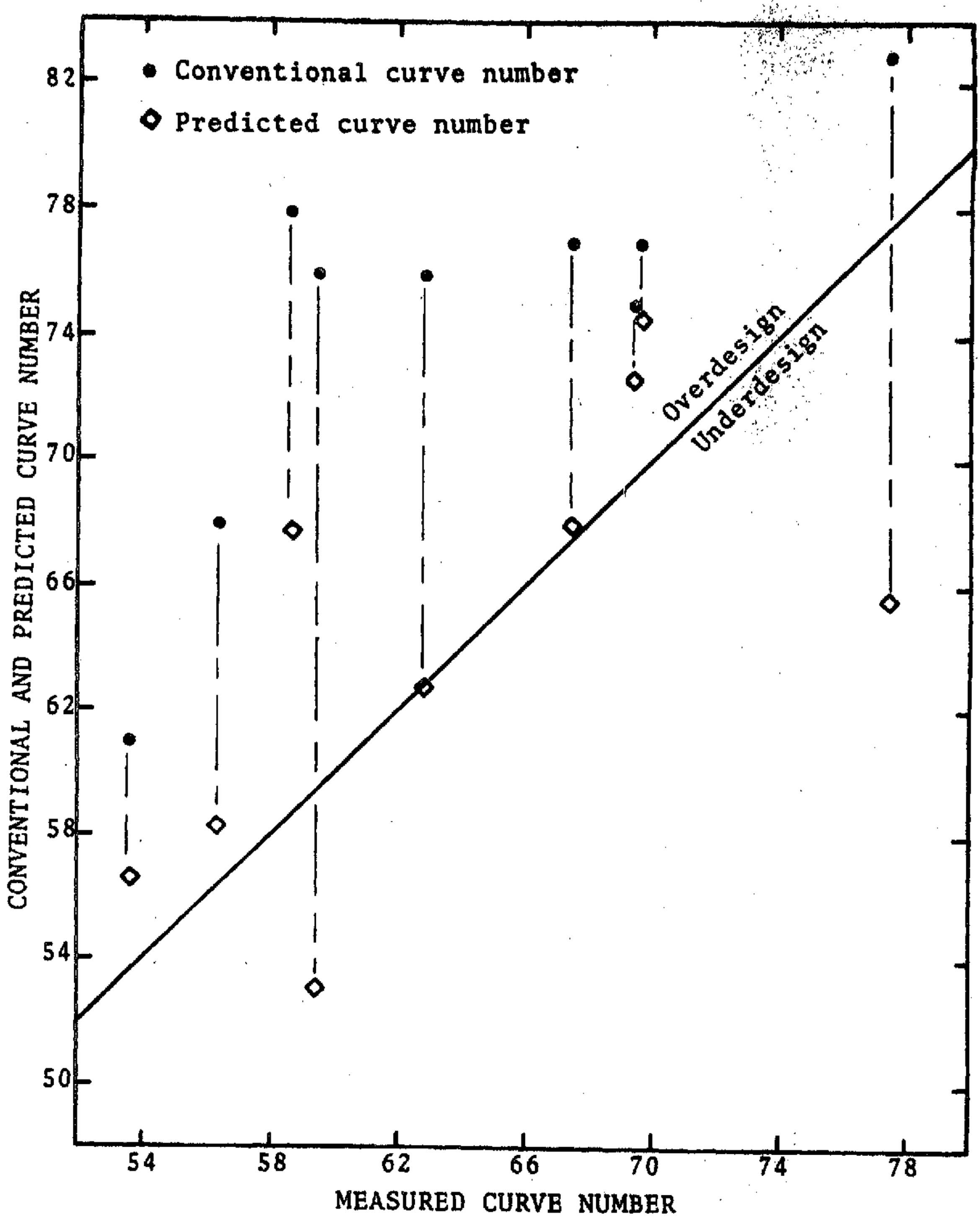

Figure 6. Comparison of conventional SCS curve numbers to curve numbers predicted with 2 bands of ERTS-MSS data (Scene 1400).

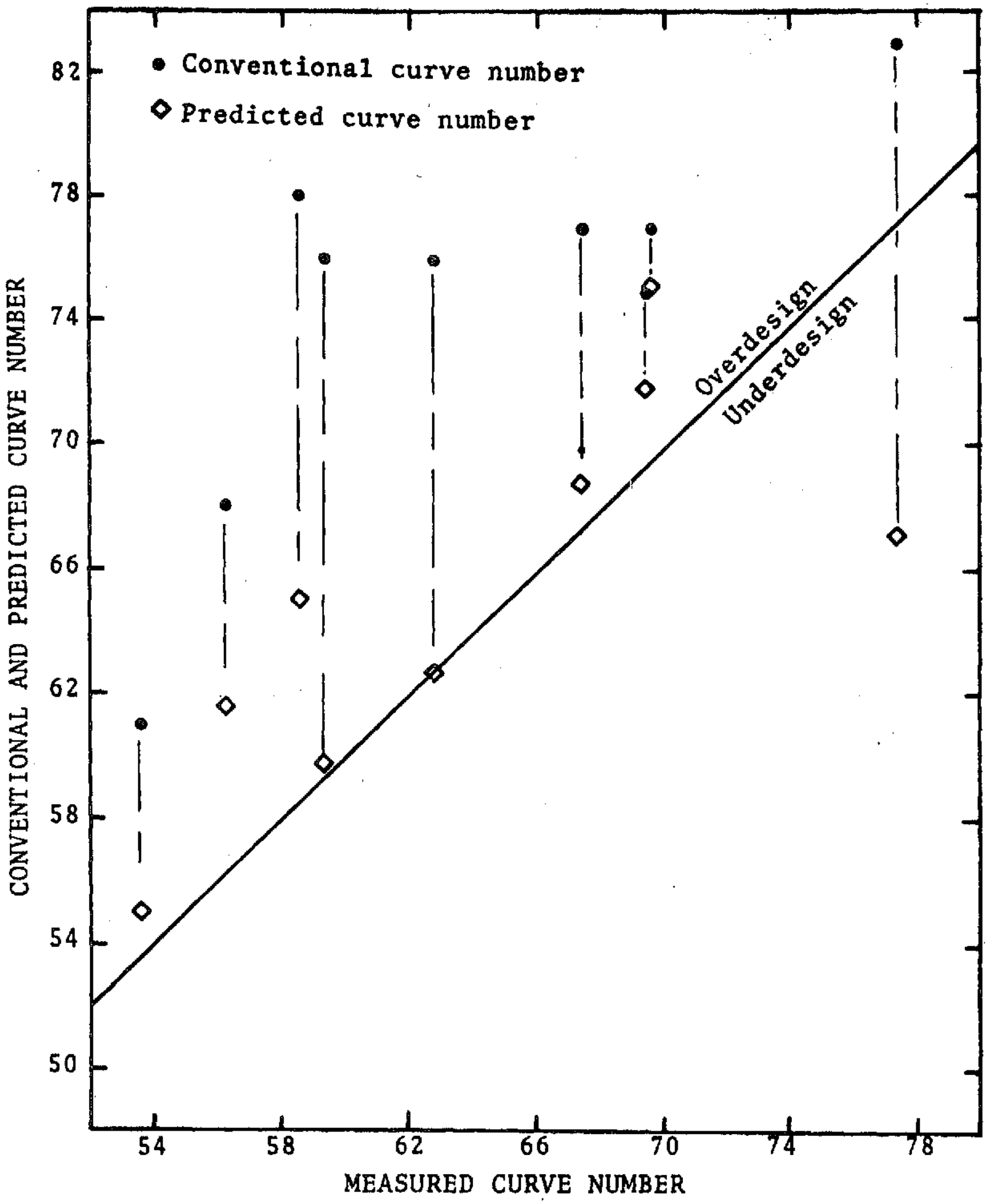

Figure 7. Comparison of conventional SCS curve numbers to curve numbers predicted with 4 bands of ERTS-MSS data (Scene 1400).

Table 4. Measured and Predicted Runoff Coefficients - Group II

Watershed No.	206	208	121	311	511	5142	5143	5144	611	621
<u>Scene 1058</u>										
Predicted CN ($\mu_5-\mu_4$)	49.6	69.0	62.2	72.9	70.6	62.9	49.0	60.6	64.6	69.6
Predicted CN ($\mu_5+\mu_6-\mu_4-2\mu_7$)	51.6	68.8	58.1	72.8	69.8	63.9	49.1	62.9	65.6	68.5
<u>Scene 1400</u>										
Predicted CN ($\mu_5-\mu_4$)	56.7	65.8	67.9	71.6	72.8	53.3	58.4	62.9	--	68.0
Predicted CN ($\mu_5+\mu_6-\mu_4-2\mu_7$)	55.0	67.2	65.1	75.1	71.9	59.8	61.6	62.7	--	68.8
Measured CN	53.6	77.4	58.6	69.6	69.4	59.4	56.3	62.8	70.2	67.4
SCS CN	61.	83.	78.	77.	75.	76.	68.	76.	77.	77.

5.4 Secondary Testing of the Prediction Scheme

In the introduction it was mentioned that runoff into a large number of flood detention structures on Sugar Creek was normally about one-half what was expected when the structures were designed. To further check this prediction scheme, the digital data for the subwatersheds on Sugar Creek watershed No. 121 were examined. Data from scene 1058 was used. A grey scale map of the Sugar Creek area was printed and an overlay was used (Fig. 8) to select data points within each small watershed. The mean difference between values of band 5 and band 4 was calculated for each subwatershed.

Long-term hydrologic data on the subwatersheds was not available. A severe storm had occurred over the area in 1965 where rainfall records from a 3-mile rain gage grid were available and high water marks in the flood detention structures had been collected. The change in storage volume and the weighted rainfall were used calculate the measured runoff curve numbers. Curve numbers based on this type of data are not considered as reliable as curve numbers calculated from long-term records. Using the mean difference calculated for each subwatershed from the MSS data as entry points to the prediction curve in figure 2A, a predicted runoff curve number for each subwatershed was obtained. The conventional SCS curve numbers and predicted values were plotted versus the measured curve number (Fig. 9) to illustrate the improvement possible by using the ERTS, MSS data.

Figure 8. Grey scale printout with map overlay of the Sugar Creek subwatersheds used to test the prediction of runoff curve numbers with ERTS-MSS data.

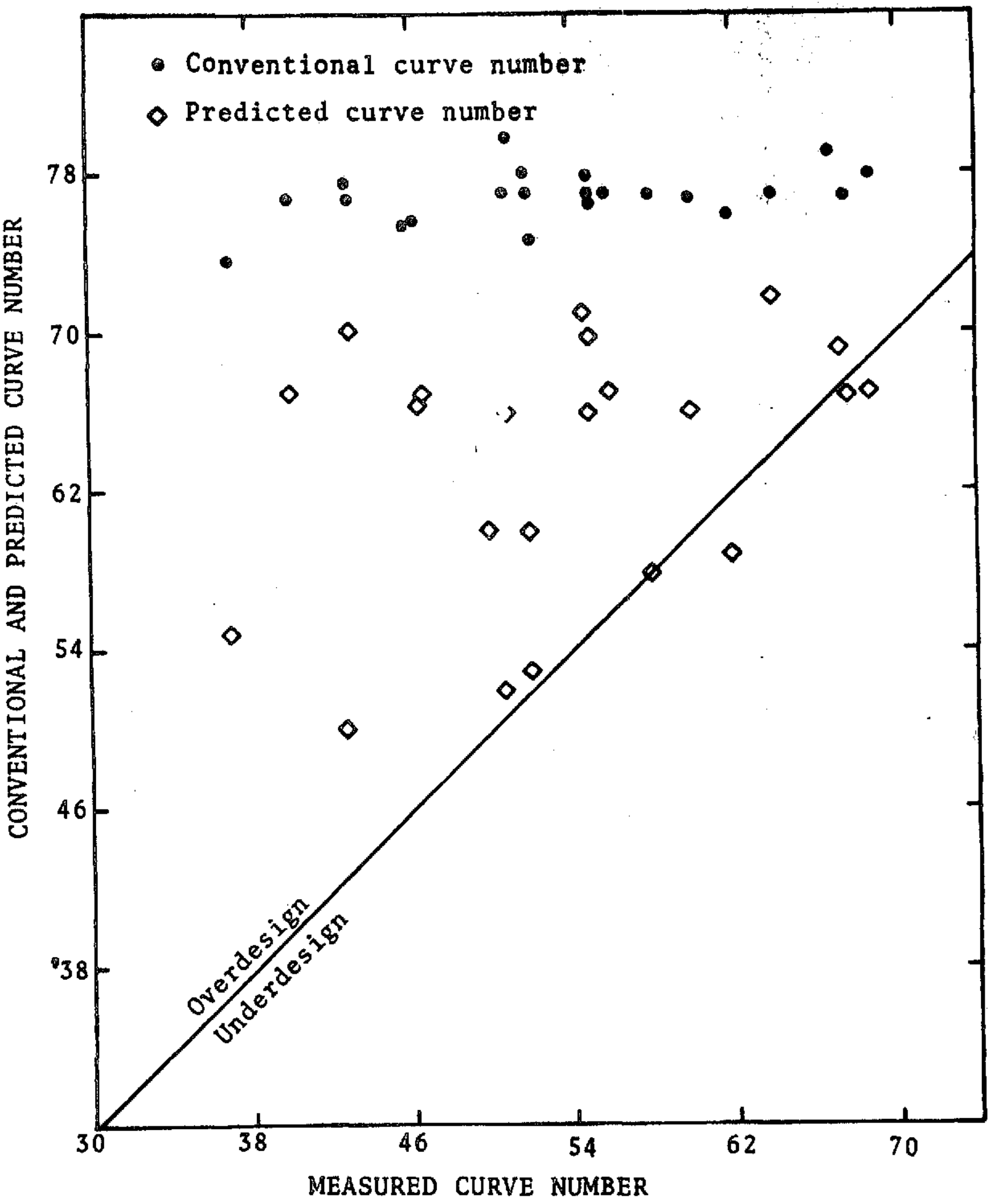

Figure 9. Comparison of SCS design watershed runoff curve numbers to curve numbers predicted using 2 bands of ERTS-MSS data.

The average absolute deviation of predicted values from the measured runoff curve numbers was 10.18. Average deviations of the conventional curve numbers for the subwatersheds was 24.08. Figure 9 shows that only 3 of the 22 subwatersheds have predicted values slightly under their measured value.

6.0 Comments and Conclusions

At the time this experiment was proposed, several factors important to the outcome were not fully recognized. First, it seemed that the multiple discriminant analysis computer programs could be used to find the ultimate equation that would define the relationship of ERTS-MSS data to watershed runoff coefficients. These programs will identify the variables that obtain best discrimination between members of a group, however, the dependent variable is not confined to a ranking. When more than two sets of watershed data are used, a linear combination of the independent variables may produce the best discrimination, but result in a change in the ranking of the dependent variable. The system, therefore, is excellent as a search routine using the high and low runoff-producing watersheds to indicate feasible linear combinations of the MSS data. In its present form the program does not necessarily indicate the best linear combination for prediction of the dependent variable when several watersheds are considered.

Secondly, it was assumed that an empirical equation including more storm parameters than rainfall amounts would predict storm runoff better than the SCS runoff equation. The data available for the 20 watersheds was not adequate to develop an equation that produced improved results. Equation 2 includes the influence of antecedent precipitation which is not incorporated in the SCS equation, and still does not produce better estimates of storm runoff than the SCS equation.

The quality and number of usable scenes of the ERTS-MSS data was also underestimated prior to the launch. In fact, it now seems that the lack of adequate long-term rainfall and runoff records on small watersheds may, in some instances, be the limiting factor in making full use of MSS data for watershed runoff estimates. To calibrate the ERTS data and apply the technique developed in this study, records are necessary on several watersheds with a range of runoff producing capability from the lowest to highest runoff curve numbers within each ERTS scene.

The similarity of the curves in figures 3 and 4 indicate that the technique used in this study is repeatable in scenes where dry surface conditions exist. The slope of the curves in these figures also illustrate the fact that the prediction curves based on spectral differences using all four bands of data are more sensitive than curves based on two bands. The digital values in all bands for scene 1400 were very large in comparison to the digital values in scene 1058. The shift of digital values from one scene to another is evident in all seven scenes, but the shift does not seem related to surface moisture conditions.

The good relationship between the linear combinations of digital data occurred only in the dry scenes. Table 1 shows that scenes from the late spring or summer when vegetative growth was heavy were all representative of relatively wet conditions. These data are inadequate to isolate the influence of vegetative growth, thus, heavy vegetation must at present be considered as a possible limiting factor in application of this technique. These data do indicate that wet surface conditions limit the application of the technique during the dormant season. Scenes 1094 and 1184 represent essentially the same sparse vegetative cover that existed in scene 1058, but both winter scenes represent wet surface soils.

The relationships developed with scene 1058 data do not exist in the wet scenes.

When the prediction scheme was tested on the Group II watersheds, both linear combinations of MSS bands predicted runoff curve numbers better than the conventional calculated curve numbers. When predictions based on two bands of data (Figs. 4 and 6) are compared to predictions from all four bands (Figs. 5 and 7), it is apparent that the four-band system underpredicts less frequently. Underprediction of curve numbers by more than five units may produce unexpected high flows through the emergency spillway of flood detention dams that may peopardize the structure. The most desirable prediction scheme would produce values that would fall on or immediately above the optimum design line in these figures. To reduce the risk of underdesign in an operational system, the prediction curve (Figs. 3 and 4) could be shifted to the right until all data points fall on the left side of the curve.

The testing of the predictions for the 22 subwatersheds of Sugar Creek offers more substantial proof of the validity of the technique. These subwatersheds are all above existing SCS flood detention reservoirs and represent a range of drainage area size common to structures built by SCS under present laws. Figure 9 illustrates that predictions based on ERTS data reduced overestimation of curve numbers by more than a factor of 2.36. Curve numbers underpredicted were 1.2, .45, and 3.0 units below curve numbers determined by the one severe storm. These underpredictions would not be considered serious.

Due to the form of the SCS equation, the influence of the improved curve numbers is nonlinear. If a watershed has an actual curve number of 50, an overestimation of 20 units will produce a calculated runoff of approximately 7.12 cm from a 15.24 cm rainfall, while an overestimation of 10 will produce calculated runoff of approximately 4.8 cm. The actual runoff would be approximately 2.9 cm. The storage volume would be overestimated 146 percent for 20 units change in curve number and only 68 percent for a change of 10 units. The improvement in prediction of runoff is greater than the linear improvement in the estimation of the curve numbers.

In summary, this study has shown that when dry surface conditions exist, linear combinations of MSS digital data can repeatedly be related to the watershed runoff coefficient used in the SCS storm runoff equation. Predictions based on the relationship between ERTS-MSS data and measured watersheds can improve SCS runoff curve numbers by more than a factor of two over curve numbers calculated by the subjective conventional methods. The improvement in estimating curve numbers can significantly improve estimates of runoff necessary for the design of flood control structures. The technique developed in this study may be limited by reflectance from dense vegetation and should be tested to define the influence of dense vegetation on the results.

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APPENDIX

SUMMARY OF ERTS-MSS MEANS,STANDARD DEVIATION,RUNOFF COEFFICIENTS

ERTS ORBIT NUMBER 1058 ON 9 19 72

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
					GROUP I						
205	31.00	31.18	36.36	17.97	1.64	2.21	2.21	0.77	54.4	61.	0.039
207	32.09	37.26	39.83	18.91	1.78	3.45	2.53	1.00	75.8	86.	0.122
111	31.39	31.88	39.73	19.74	4.38	7.89	6.30	3.15	60.9	71.	0.038
141	28.85	29.28	37.81	19.03	3.36	7.34	1.01	3.34	58.0	74.	0.023
512	29.72	31.38	36.08	17.69	2.45	5.38	4.01	1.88	67.2	74.	0.050
513	29.16	30.25	35.57	17.55	2.36	5.14	3.66	1.66	65.7	74.	0.054
5141	29.43	30.24	34.71	17.09	2.09	4.12	3.00	1.29	61.5	74.	0.041
5146	29.41	30.16	35.07	17.27	2.20	4.00	2.67	1.11	63.8	73.	0.068
522	30.39	30.28	37.04	18.43	4.80	7.39	4.99	2.32	57.1	73.	0.031
612	30.74	32.71	38.71	18.86	2.39	4.77	4.76	2.68	66.7	74.	0.057
					GROUP II						
WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	30.63	30.19	36.19	18.06	1.41	2.04	1.94	0.62	53.6	61.	0.034
208	30.08	32.38	35.81	17.42	2.08	3.14	2.79	1.10	77.4	83.	0.147
121	30.44	31.08	41.04	20.64	8.37	11.21	10.38	5.46	58.6	78.	0.023
311	32.49	36.32	38.66	18.57	2.90	5.31	4.57	2.23	69.6	77.	0.078
511	30.72	33.61	38.52	18.82	2.82	6.02	4.64	2.16	69.4	75.	0.082
5142	29.14	29.92	34.80	17.14	1.77	4.20	3.27	1.22	59.4	76.	0.027
5143	28.86	28.30	32.88	16.51	1.65	2.82	2.27	1.10	56.3	68.	0.021
5144	29.57	30.28	34.80	17.12	2.22	4.03	2.89	1.24	62.8	76.	0.066
611	32.32	33.40	38.65	18.87	3.50	5.42	5.02	2.70	70.2	77.	0.065
621	29.72	32.28	38.40	18.93	2.68	6.39	5.03	2.33	67.4	77.	0.057

WS ----- WATERSHED NUMBER

COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF

COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE

COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS,STANDARD DEVIATION,RUNOFF COEFFICIENTS
ERTS ORBIT NUMBER 1094 ON 10 25 72

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	29.96	29.13	30.83	15.30	1.52	1.84	1.53	0.88	54.4	61.	0.039
207	28.07	29.07	29.20	14.20	0.88	2.40	1.66	1.01	75.8	86.	0.122
111	27.72	26.23	30.13	15.00	2.65	4.92	4.19	2.17	60.9	71.	0.038
141	26.75	25.56	29.28	14.76	2.49	4.62	4.15	2.46	58.0	74.	0.023
512	26.65	25.45	27.35	13.42	1.62	3.00	2.61	1.43	67.2	74.	0.050
513	26.45	25.07	27.18	13.37	1.62	2.94	2.52	1.40	65.7	74.	0.054
5141	26.65	25.15	26.82	13.15	1.48	2.38	2.04	1.12	61.5	74.	0.041
5146	26.38	24.71	26.74	13.16	1.49	2.32	1.91	1.05	63.8	73.	0.068
522	26.93	24.90	27.15	13.32	2.42	3.63	3.82	2.17	57.1	73.	0.031
612	26.88	25.11	27.62	13.78	1.76	3.01	1.94	1.07	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	28.45	26.90	29.07	14.66	1.09	1.61	1.93	0.77	53.6	61.	0.034
208	26.83	26.03	27.67	13.43	1.44	1.79	1.97	1.10	77.4	83.	0.147
121	26.84	26.21	30.08	15.14	2.77	5.58	4.67	2.48	58.6	78.	0.023
311	27.20	26.43	27.10	13.19	2.11	3.28	3.99	2.23	69.6	77.	0.078
511	27.12	26.57	28.36	13.91	1.80	3.15	2.94	1.57	69.4	75.	0.082
5142	26.88	25.90	27.34	13.41	1.33	2.54	2.30	1.11	59.4	76.	0.027
5143	26.68	24.88	26.20	12.95	1.39	1.98	1.75	0.98	56.3	68.	0.021
5144	26.58	25.00	26.81	13.14	1.52	2.39	1.97	1.10	62.8	76.	0.066
611	26.47	24.42	27.32	13.51	1.47	2.68	2.42	1.40	70.2	77.	0.065
621	26.17	25.26	27.91	13.82	1.65	3.45	2.88	1.54	67.4	77.	0.057

WS ----- WATERSHED NUMBER
COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF
COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE
COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS, STANDARD DEVIATION, RUNOFF COEFFICIENTS
ERTS ORBIT NUMBER 1184 ON 1 23 73

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	20.50	20.96	22.62	11.88	1.14	1.04	1.92	1.28	54.4	61.	0.039
207	19.52	21.10	21.81	11.52	0.68	1.58	1.25	0.93	75.8	86.	0.122
111	21.06	21.04	22.77	11.83	2.23	5.66	3.99	2.16	60.9	71.	0.038
141	19.88	19.75	21.55	11.42	2.09	4.05	4.39	2.48	58.0	74.	0.023
512	19.62	19.14	20.63	10.77	1.10	2.12	2.93	1.81	67.2	74.	0.050
513	19.58	19.08	20.52	10.74	1.11	2.13	3.02	1.89	65.7	74.	0.054
5141	19.64	19.00	20.02	10.41	1.08	1.83	2.13	1.33	61.5	74.	0.041
5146	19.57	18.83	19.77	10.35	1.10	2.00	2.21	1.38	63.8	73.	0.063
522	20.66	20.15	22.43	11.84	2.39	3.92	4.24	2.30	57.1	73.	0.031
612	19.69	19.45	21.19	11.25	1.17	2.52	3.21	1.86	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	20.41	20.48	22.52	12.07	0.82	0.91	1.57	1.13	53.6	61.	0.034
208	19.31	19.00	19.88	10.19	0.93	1.36	1.18	0.98	77.4	83.	0.147
121	19.83	19.86	21.97	11.54	2.33	4.71	4.47	2.33	58.6	78.	0.023
311	19.78	19.50	22.01	11.61	1.18	2.16	2.44	1.46	69.6	77.	0.078
511	19.86	19.77	21.85	11.45	1.33	2.32	2.84	1.69	69.4	75.	0.082
5142	20.71	20.65	22.37	11.75	1.52	2.27	2.48	1.45	59.4	76.	0.027
5143	20.10	19.85	20.70	10.76	0.97	1.35	1.97	1.33	56.3	68.	0.021
5144	19.51	18.71	19.72	10.28	1.10	1.97	2.18	1.38	62.8	76.	0.066
611	19.73	19.20	21.12	11.03	1.18	2.19	2.92	1.79	70.2	77.	0.065
621	19.58	19.81	21.26	11.09	1.18	2.75	3.20	1.83	67.4	77.	0.057

WS ----- WATERSHED NUMBER
COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF
COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE
COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS,STANDARD DEVIATION,RUNOFF COEFFICIENTS

ERTS ORBIT NUMBER 1256 ON 4 5 73

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	30.81	30.78	41.30	22.81	1.04	2.10	2.71	1.44	54.4	61.	0.039
207	34.38	43.43	49.81	26.29	2.40	5.26	3.17	1.79	75.8	86.	0.122
111	33.18	34.41	45.85	25.06	4.27	8.56	7.51	4.55	60.9	71.	0.038
141	31.34	34.02	42.46	22.90	3.62	8.02	8.57	4.90	58.0	74.	0.023
512	30.21	31.03	38.54	20.68	1.89	4.56	7.05	4.69	67.2	74.	0.050
513	30.18	30.98	37.06	19.72	1.77	3.93	5.98	3.90	65.7	74.	0.054
5141	30.18	30.72	35.53	18.82	1.42	2.73	4.10	2.48	61.5	74.	0.041
5146	30.16	30.83	35.61	18.92	1.55	2.70	4.11	2.56	63.8	73.	0.068
522	32.65	32.71	43.59	23.89	7.58	7.65	7.36	4.31	57.1	73.	0.031
612	30.50	31.29	42.20	22.97	1.73	4.23	6.05	3.95	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	30.84	31.06	39.81	21.84	1.10	3.09	2.15	1.32	53.6	61.	0.034
208	30.22	33.22	39.19	20.63	1.19	3.43	4.28	2.66	77.4	83.	0.147
121	32.55	36.40	45.71	24.48	4.53	9.96	9.31	5.10	58.6	78.	0.023
311	31.06	31.22	47.40	26.36	3.35	7.77	6.05	4.28	69.6	77.	0.078
511	30.62	31.39	43.59	23.76	2.93	6.98	6.92	4.67	69.4	75.	0.082
5142	30.27	30.01	34.52	18.31	1.33	2.46	3.88	2.62	59.4	76.	0.027
5143	30.45	30.63	34.88	18.36	1.16	2.30	3.45	2.15	56.3	68.	0.021
5144	30.05	30.64	35.61	18.87	1.46	2.80	4.22	2.61	62.8	76.	0.066
611	29.98	30.43	38.38	20.90	1.91	4.66	5.99	4.07	70.2	77.	0.065
621	30.84	33.94	41.10	21.74	2.15	5.87	6.90	4.09	67.4	77.	0.057

WS ----- WATERSHED NUMBER
COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF
COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE
COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS,STANDARD DEVIATION,RUNOFF COEFFICIENTS
ERTS ORBIT NUMBER 1274 ON 4 23 73

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	31.41	27.83	43.28	23.14	0.78	1.87	1.87	1.30	54.4	61.	0.039
207	31.67	34.44	43.78	21.72	0.97	3.40	2.16	1.32	75.8	86.	0.122
111	33.42	31.90	47.52	25.13	3.58	7.82	6.53	4.28	60.9	71.	0.038
141	33.35	34.25	47.04	24.57	6.37	8.84	7.95	4.71	58.0	74.	0.023
512	30.92	28.68	40.10	20.82	4.24	3.71	5.97	4.24	67.2	74.	0.050
513	31.02	29.02	38.80	19.98	4.30	3.40	5.15	3.57	65.7	74.	0.054
5141	31.39	29.10	37.54	19.22	5.07	2.35	3.46	2.23	61.5	74.	0.041
5146	32.46	29.04	38.13	19.68	8.62	2.25	3.55	2.23	63.8	73.	0.068
522	31.99	28.23	44.42	23.58	6.41	5.78	5.42	3.78	57.1	73.	0.031
612	30.29	27.71	43.57	23.06	1.63	4.12	5.00	3.76	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	31.48	28.00	42.48	22.91	0.91	1.37	1.87	1.38	53.6	61.	0.034
208	31.26	30.84	39.05	19.89	0.73	3.02	3.36	2.21	77.4	83.	0.147
121	34.96	37.86	50.41	26.08	7.45	11.04	9.07	5.41	58.6	78.	0.023
311	31.86	28.19	49.83	27.39	7.69	7.61	6.34	4.93	69.6	77.	0.078
511	30.63	27.40	43.66	23.26	5.84	5.21	6.19	4.73	69.4	75.	0.082
5142	31.11	28.90	36.51	18.51	1.09	2.71	3.10	2.01	59.4	76.	0.027
5143	31.16	29.31	36.54	18.49	1.10	2.11	3.01	1.92	56.3	68.	0.021
5144	32.30	29.22	37.60	19.26	8.59	2.39	3.43	2.20	62.8	76.	0.066
611	30.01	27.08	40.28	21.02	1.62	3.96	5.63	3.99	70.2	77.	0.065
621	30.66	30.36	41.13	21.00	1.56	4.40	5.31	3.52	67.4	77.	0.057

WS ----- WATERSHED NUMBER
COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF
COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE
COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS, STANDARD DEVIATION, RUNOFF COEFFICIENTS

ERTS ORBIT NUMBER 1400 ON 8 27 73

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	37.40	31.60	46.30	24.06	0.77	2.80	1.39	0.78	54.4	61.	0.039
207	38.74	38.74	50.58	24.63	1.19	3.63	2.32	0.76	75.8	86.	0.122
111	39.56	37.20	48.52	24.07	2.08	5.93	4.41	2.86	60.9	71.	0.038
141	37.09	32.41	47.61	24.20	2.08	5.48	4.81	3.01	58.0	74.	0.023
512	37.10	33.15	45.82	22.86	1.62	6.60	3.28	2.07	67.2	74.	0.050
513	36.92	33.00	45.27	22.55	1.34	6.53	2.85	1.75	65.7	74.	0.054
5141	37.16	32.44	45.23	22.61	1.41	6.68	2.26	1.34	61.5	74.	0.041
5146	37.02	32.11	45.54	23.16	1.86	9.22	2.23	1.32	63.8	73.	0.068
522	38.61	33.23	49.84	25.31	1.35	7.10	3.67	2.57	57.1	73.	0.031
612	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	37.21	31.75	46.64	24.11	1.13	2.05	1.66	0.88	53.6	61.	0.034
208	37.09	33.04	46.64	22.95	0.92	1.59	1.62	1.17	77.4	83.	0.147
121	37.69	34.29	49.71	25.30	2.57	5.88	7.22	4.83	58.6	78.	0.023
311	40.08	39.44	46.80	22.69	2.24	7.00	3.95	2.67	69.6	77.	0.078
511	37.93	36.34	47.06	23.30	1.64	7.40	4.03	2.68	69.4	75.	0.082
5142	37.10	31.32	44.64	22.34	1.50	2.60	2.14	1.14	59.4	76.	0.027
5143	36.94	31.64	44.40	22.22	1.18	2.95	2.10	1.25	56.3	68.	0.021
5144	37.01	32.36	45.38	22.86	1.55	9.11	2.19	1.33	62.8	76.	0.066
611	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	70.2	77.	0.065
621	38.39	35.01	46.13	22.73	2.17	6.90	4.27	2.64	67.4	77.	0.057

WS ----- WATERSHED NUMBER

COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF

COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE

COEF3 -- COEFICIENT FOR EQUATION 2

SUMMARY OF ERTS-MSS MEANS, STANDARD DEVIATION, RUNOFF COEFFICIENTS

ERTS ORBIT NUMBER 1508 ON 12 13 73

GROUP I

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
205	19.15	20.31	23.15	11.69	1.01	1.81	2.17	0.88	54.4	61.	0.039
207	19.86	22.36	24.82	12.41	0.99	2.15	2.10	1.30	75.8	86.	0.122
111	19.20	18.86	22.94	11.86	2.07	3.75	5.12	2.95	60.9	71.	0.038
141	18.22	17.41	20.34	10.46	1.84	3.56	4.99	2.88	58.0	74.	0.023
512	17.76	17.30	19.88	10.20	1.32	2.64	4.29	2.46	67.2	74.	0.050
513	17.65	17.08	19.37	9.92	1.22	2.44	4.02	2.32	65.7	74.	0.054
5141	17.62	17.11	18.80	9.64	1.15	2.33	2.78	1.49	61.5	74.	0.041
5146	17.25	16.38	17.75	9.13	1.05	1.99	2.64	1.43	63.8	73.	0.068
522	18.85	18.37	21.64	11.17	2.06	3.70	5.06	2.80	57.1	73.	0.031
612	17.85	17.24	19.81	10.21	1.33	2.50	3.79	2.09	66.7	74.	0.057

GROUP II

WS	MSS-4	MSS-5	MSS-6	MSS-7	SD-4	SD-5	SD-6	SD-7	COEF1	COEF2	COEF3
206	18.78	19.04	21.86	11.21	0.74	1.82	1.56	0.88	53.6	61.	0.034
208	18.11	19.07	20.89	10.59	1.12	2.28	2.42	1.31	77.4	83.	0.147
121	18.49	18.22	21.79	11.17	2.12	4.41	5.50	3.05	58.6	78.	0.023
311	18.75	18.23	23.38	12.13	1.35	2.66	4.01	2.46	69.6	77.	0.078
511	18.75	18.60	22.91	11.83	1.63	3.27	4.84	2.86	69.4	75.	0.082
5142	17.62	17.42	19.10	10.01	0.97	2.09	2.29	1.30	59.4	76.	0.027
5143	17.81	17.72	19.49	10.08	1.04	2.27	2.61	1.36	56.3	68.	0.021
5144	17.32	16.56	18.02	9.22	1.03	2.03	2.59	1.38	62.8	76.	0.066
611	18.01	17.50	19.82	10.20	1.40	2.50	4.08	2.42	70.2	77.	0.065
621	18.24	18.53	20.71	10.48	1.57	3.27	4.29	2.30	67.4	77.	0.057

WS ----- WATERSHED NUMBER
COEF1 -- SCS CURVE NUMBER CALCULATED FROM MEASURED RAINFALL AND RUNOFF
COEF2 -- SCS CURVE NUMBER DERIVED BY CONVENTIONAL SCS TECHNIQUE
COEF3 -- COEFICIENT FOR EQUATION 2

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MERGE

```
      INTEGER RSKIP,TAPID
      DIMENSION IDD(3600),ID(1800),IO(1800),IL(1800)
      DIMENSION ITABL(5),IDSBF(11),IOTBL(3),IM(5),IDENT(13)
      EQUIVALENCE(IDD(1),ID(1)),(IDD(1801),IO(1)),(IM(5),IDD(1))
      DATA IDENT/-1,0,4,5,6,7,'ER','TS','A '/
      DATA ITABL/'E ','UC','BR',5,1/
      READ(2,10)RSKIP,NOEFT,NOELT,NRTCY,TAPID
   10 FORMAT(14I5)
      CALL DSOR(ITABL(5),IDSBF(11),ICOMP)
      IDENT(2)=TAPID
      IM(4)=TAPID
      IM(2)=IDENT(7)
      IM(3)=IDENT(8)
      IOTBL(3)=1
      IOTBL(2)=0
      IDENT(10)=RSKIP
      IDENT(11)=NOEFT
      IDENT(12)=NOELT
      IDENT(13)=NRTCY
      LL=NOEFT+NOELT
      IOTBL(1)=-(LL+LL)
      DO 2 I=1,2
      J=I-1
      DO 2 K=1,RSKIP
      CALL MGTAP(J,2,IO,1800,NO)
      IF(NO)2,200,2
    2 CONTINUE
      DO 20 I=1,NRTCY
      CALL MGTAP(0,2,IO,1800,NO)
      IF(NO)3,100,5
    3 NO=1648
    5 NO=NO-28
      M=NO-NOEFT+1
      CALL MOVE(IO,M,NO,ID,1)
```

MERGE CONTINUED

```
      CALL MGTAP(1,2,IL,1800,NO)
      IF(NO)15,100,15
 15   M=NOEFT+1
      CALL MOVE(IL,1,NOELT,ID,M)
      CALL WDDSK(I,ID(LL),IOTBL(3),IDSBF(11),ICOMP)
 20   CONTINUE
100   CALL MGTAP(0,6,IL,9,NO)
      CALL MGTAP(1,6,IL,9,NO)
      DO 25 I=1,RSKIP
      CALL MGTAP(0,2,IL,1800,NO)
      IF(NO)25,200,25
 25   CONTINUE
 27   CALL MGTAP(1,3,IDENT,13,NO)
      IF(NO)27,200,28
 28   CONTINUE
      DO 50 I=1,NRTCY
      CALL MGTAP(0,2,IL,1800,NO)
      IF(NO)29,200,30
 29   NO=1648
 30   NO=NO-28
      CALL RDDSK(I,IDD(LL),IOTBL(3),IDSBF(11),ICOMP)
      K=NOEFT+NO+1
      CALL MOVE(IDD,M,LL,IDD,K)
      CALL MOVE(IL,1,NO,IDD,M)
      K=LL+NO+4
      IM(1)=I
 35   CALL MGTAP(1,3,IM ,K,NO)
      IF(NO)35,200,50
 50   CONTINUE
      CALL MGTAP(1,8,IDD,9,NO)
200   CALL MGTAP(0,6,IDD,9,NO)
      CALL MGTAP(1,6,IDD,9,NO)
      CALL EXIT
      END
```

ORIGINAL PAGE IS OF POOR QUALITY

```
*****************************************************
*                                                   *
*        IBM 1800 MAGNETIC TAPE I/O ROUTINE         *
*                                                   *
* THE FOLLOWING ROUTINE WILL ALLOW THE USER TO      *
* READ BINARY TAPES IN FORTRAN OR ASSEMBLER.        *
* THIS ROUTINE HAS BEEN SUCCESSFULLY USED TO READ   *
* TAPES CREATED ON IBM 360'S, DEC 10'S, AND UNIVAC*
* 1100 SERIES COMPUTERS.                            *
*                                                   *
*              AUTHOR--                             *
*                          ROBERT J TORLINE         *
*                          USDA-ARS                 *
*                          P O BOX 267              *
*                          WESLACO, TX 78596        *
*                          512-968-5533 EXT 53      *
*                                                   *
*                          COMMON USER NO 3080      *
*                                                   *
* MAJOR REVISION   VER 4   DATE OF LAST CHANGE      *
* MINOR REVISION   MOD 1      FEB 22, 1974          *
*****************************************************
      ENT      MGTAP (IUNIT,IFUNC,ID,MAX,NO)
MGTAP DC       *-*
      STX    1 XR1+1
      LDX   I1 MGTAP
      LD    I1 1             OPERATION CODE
      STO      MGTAP
      SLA      12
      OR    I1 0             DRIVE NUMBER
      STO      CONTR         CONTROL WORD
      LD    I1 3             VALUE OF RECORD LENGTH OR
      STO      RL            MAX DIMENSION OF I/O ARRAY
      LD     1 2             ADDRS OF END I/O TABLE
```

ORIGINAL PAGE IS
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```
      STO      NAME+1
      S        RL
      STO      IOADD        ADDRS BEGINNING I/O TABLE
      LD     1 4            ADDRS OF ACTUAL REC LENGTH
      STO      RETRN+1      OR COMPLETION CODE
      STS   I  IOADD,/40    UNSTORAGE PROTECT BEGIN
      LD    I  IOADD        OF I/O TABLE
      STO      SAVE         AND SAVE CONTENTS
      LD       RL
      STO   I  IOADD
      MDX    1 5
      STX    1 BACK+1
      LD       MGTAP
      A        M3
      BN       SKIP         BRANCH ON READ NEG
      A        M1
      BP       SKIP         BRANCH ON CONTROL POS
      LD       RL
      BSI      FLIP         FLIP ARRAY BEFORE WRITE
      LD       M3           NEG FOR WRITE OR READ
SKIP  STO      MGTAP        POS OR ZERO FOR CONTROL
      CALL     P2401
CONTR DC       *-*
IOADD DC       *-*
RETRN STO   L  *-*          STO COMPLETION CODE
      BNP      TEST         IF NOT CORRECT WORD COUNT
      LD       MGTAP          TEST, IF READ OR WRITE
      BNN      XR1          SET UP TO FLIP ARRAY
      LD    I  RETRN+1
FLOP  BSI      FLIP
XR1   LDX   L1 *-*
      LD       SAVE
      STO   I  IOADD        RESTORE SAVED WORD
BACK  BSC   L  *-*
SAVE  DC       *-*
```

```
RL     DC        *-*
M3     DC        -3
M1     DC        -1
FLIP   DC        *-*          ROUTINE TO FLIP ARRAY
       STX     2 XR2+1
       STX     3 XR3+1
       STO       COUNT+1
       LD        RL
       SRA       1
       CMP       COUNT+1
       MDX       NAME
       STO       COUNT+1      FOR 360 COMPATABILITY
NAME   LDX    L1 *-*          DATA ARRAYS MUST BE
       LDX    I2 IOADD        FLIPPED AFTER READS AND
COUNT  LDX    L3 *-*          BEFORE AND AFTER WRITES.
LOOP   MDX     2 1            ---------- NOTE ----------
       LD      1 0            -                        -
       XCH                    - IF AN ERROR OCCURS ON  -
       LD      2 0            - A WRITE COMMAND THE    -
       STO     1 0            - DATA ARRAY WILL RETURN -
       XCH                    - TO THE CALLING PROGRAM -
       STO     2 0            - AS IT WAS BEFORE THE   -
       MDX     1 -1           - CALL.              RJT -
       MDX     3 -1           --------------------------
       MDX       LOOP
XR2    LDX    L2 *-*
XR3    LDX    L3 *-*
       BSC    I  FLIP
TEST   LD        MGTAP        ON ERROR TEST FOR WRITE
       S         M3           COMMAND (READ WILL BE A
       BNZ       XR1          -1 OR -2). IF WRITE SET UP
       LD        RL           TO FLIP THE ARRAY AND
       MDX       FLOP         RETURN IT AS BEFORE.
       END
```

```
        ENT        P2401
P2401   DC         *-*           CALL P2401
        STX    1   XR1+1         DC   /HEX    CONTROL
        LDX   I1   P2401         DC   ADDRS
        LD     1   0
        TTO        CONTL
        LD     1   1             ACCUM =   + WORD COUNT
        STO        ADDRS                   0 EOF
        MDX    1   2                       -1  WLR
        STX    1   BACK+1                  -2  R/W ERROR
CALL    CALL       MAGT          2401      -3  END OF TAPE
        DC         LIST                    -4  FILE PROTECT
        MDX        *+2                     -5  REQUEST ABOR
BUSY    LD         *
        DC         /3045
        LD         LIST
        BSC    L   BUSY,Z
        LD         LIST+6
        A          M1
        BZ         ZERO
        A          M1
        A          M1
        BNP        WAIT
        A          M1
        BZ         EOF
        A          M1
        BZ         WLR
        EOR        M1            CHANGE SIGN OF ERROR
        MDX        ZERO+2
WLR     LD         LIST+2
        BNN        ERROR
        A      I   ADDRS
        S          M1
        MDX        ZERO+2
```

P2401 CONTINUED

```
ERROR LD        M1
      MDX       ZERO+2
ZERO  LD    I   ADDRS
XR1   LDX   L1  *-*
BACK  BSC   L   *-*
WAIT  SLA       16
      STO   L   $PAUS
      LD        CONTL
      WAIT
      MDX   L   $PAUS,0
      MDX       WAIT
      MDX       CALL
$PAUS EQU       97
EOF   EQU       ZERO+2
M1    DC        -1
LIST  DC        0
      DC        0
      BSS       4
      DC        *-*
CONTL DC        *-*
ADDRS DC        *-*
      END
```

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MOVE

```
        ENT       MOVE MOVE SUBROUTINE ENTRY POINT
*                      CALL MOVE(JCARD,J,JLAST,KCARD,K)
*                      THE WORDS JCARD(J) THROUGH
*                      JCARD(JLAST) ARE MOVED TO KCARD
*                      STARTING AT KCARD(K).
MOVE    DC        *-*  ARGUMENT ADDRESS COMES IN HERE
        STX     1 SAVE1+1 SAVE IR1
        LDX    I1 MOVE PUT ARGUMENT ADDRESS IN IR1
        LD      1 0    GET JCARD ADDRESS
        S      I1 2    SUBTRACT JLAST VALUE
        STO       LD1+1 PLACE ADDR OF JCARD(JLAST) IN
*                      PICKUP OF MOVE
        LD     I1 2    GET JLAST VALUE
ONE     S      I1 1    SUBTRACT J VALUE
        BSC       +Z   CHECK FIELD WIDTH
        SRA       16   NEGATIVE - MAKE IT ZERO
        STO       LDX+1 STORE FIELD WIDTH IN LDX
        LD      1 3    GET KCARD ADDRESS
        S      I1 4    SUBTRACT K VALUE
        S         LDX+1 SUBTRACT FIELD WIDTH
        STO       STO+1 PLACE ADDR OF KCARD(KLAST) IN
*                      STORE OF MOVE
        MDX     L LDX+1,1       ADD ONE TO FIELD WIDTH
*                      MAKING IT TRUE
        MDX     1 5    MOVE OVER FIVE ARGUMENTS
        STX     1 DONE1+1 CREATE RETURN ADDRESS
*                      JNOW=J
*                      KNOW=K+JNOW-J
LDX     LDX    L1 *-*  LOAD IR1 WITH FIELD WIDTH
*                      KCARD(KNOW)=JCARD(JNOW)
LD1     LD     L1 *-*  PICKUP JCARD(JNOW)
STO     STO    L1 *-*  STORE IT IN KCARD(KNOW)
*                      SEE IF JNOW IS LESS THAN JLAST.
*                      IF YES, JNOW=JNOW+1 AND MOVE
```

MOVE CONTINUED

```
*                       NEXT CHARACTER.  IF NO, EXIT....
      MDX    1 -1       DECREMENT THE FIELD WIDTH
      MDX       LD1     NOT DONE - GET NEXT WORD
*                       EXIT............................
SAVE1 LDX   L1 *-*      DONE - RESTORE IR1
DONE1 BSC   L  *-*      RETURN TO CALLING PROGRAM
      END
```

```
C      ***************************************************************
C
C                  OKLAH
C         PROGRAMMED BY M. GAUTREAUX
C        USDA,WESLACO, TEXAS 78596
C
C*******************************************************************
C      OKLAH IS A PROGRAM DESIGNED TO SELECT IRREGULAR SHAPE
C      AREAS BY A SERIES OF TRAPEZOIDS USED TO APPROXIMATE THE AREA
C
C*******************************************************************
C
C         IIN    -  INPUT VECTOR
C         ISAVE  -  VECTOR USED TO SAVE WANTED DATA
C                   (DIMENSION MAY VARY DEPENDING ON AREA SIZE)
C         IDSPY  -  VECTOR USED IN DISPLAYING AREA ON DICOMED MODEL 36
C                   DISPLAY UNIT
C         IOUT   -  VECTOR USED TO CONTAIN TWO DATA PTS. CONTAIN IN ONE
C                   ERTS WORD
C         QUAD   -  VECTOR (TWO DIMENSIONAL) USED TO HOLD THE ID OF AREA
C                   AND OTHER PARAMETERS FOR THE SELECTED AREA
C         ID     -  ID VECTOR (512)
C         IPT    -  VECTOR CONTAINS THE FOUR PTS. THAT DEFINE THE AREA
C                   ( ONE TRAPEZOID AREA)
C         DENT   -  VECTOR USED TO CONVERT ID TO REAL NUMBERS
C         JTAPE  -  SECONDARY TAPE ID NUMBER ON TAPE (READ FROM TAPE)
C         ITAPE  -  SECONDARY TAPE ID NUMBER ON TAPE (READ FROM CARD)
C         IFILE  -  CURRENT NUMBER OF FILES ON SECONDARY TAPE
C         NODAT  -  NUMBER OF PASSES (REWINDS) NEEDED TO GET ALL SELECTED
C                   AREAS
C         NOSET  -  NUMBER OF AREAS TO BE SELECTED ON CURRENT PASS
C         NRCD   -  NUMBER OF RECORD THAT YOU WANT TO START WITH
C                   WILL SKIP NRCD-1 RECORDS ON ERTS TAPE
C                   USED MAINLY WITH ERTSA - BY R. TORLINE - TO TRANSFER
```

```
C                    THE Y STARTING POSITION
C          IWORD -   NUMBER OF WORDS (ONE WORD = FOUR CONSECUTIVE ERTS
C                    WORDS WHERE THE FIRST ERTS WORD WAS FOR CHANNEL ONE)
C                    USED WITH ERTSA - BY R. TORLINE - TO TRANSFER
C                    THE X STARTING POSITION
C          IFLNO -   FLIGHT NUMBER OF CURRENT ERTS TAPE
C          IH2O  -   WATERSHED NUMBER
C          IDAY  -   ------------
C          IMNTH -   DATE OF PASS BY SAT.
C          IYEAR -   ------------
C          IHSTA -   BOUNDARY PTS. OF THE LEFT - HAND SIDE OF SELECTED
C                    AREA (IHSTA = THE LOWEST X COORD.- 1)
C          IHEND -   BOUNDARY PT. OF THE RIGHT - HAND SIDE OF SELECTED
C                    AREA (IHEND = THE HIGHEST X COORD. +1)
C          IX,IY -   CORRECTION FACTORS FOR A OVERALL SHIFT
C          M     -   BLOW-UP FACTOR (FOR DISPLAY PURPOSES)
C          IH,IV -   STARTING COORD. ON DISPLAY
C          ICHAN -   CHANNEL (1-4)  SEND TO DISPLAY
C
C************************************************************************
C
        INTEGER START
      DIMENSION IIN(1800),ISAVE(3000),IDSPY(1000),IOUT(3600)
      DIMENSION QUAD(60,12),ID(10),IPT(8),E(4),PT(8),DENT(10)
      DEFINE FILE 1(200,8,U,KAPPA)
      KAPPA=1
C
C         READS IN JTAPE AND IFLE FROM SECONDARY TAPE
C
      READ(5) JTAPE,IFILE
      WRITE(3,6)JTAPE,IFILE
    6 FORMAT(2I10)
C
      READ(2,767)ITAPE,NODAT,NOSET,NRCD,IWORD
  767 FORMAT(5I5)
```

```
C
      KKK=0
      MAX=1800
C
C        CHECKS FOR CORRECT SECONDARY TAPE
C
      IF(JTAPE-ITAPE)600,601,600
  601 CALL W1322(5,2)
      IF(IFILE-1)610,620,620
  620 LFILE=IFILE+1
C
C        SKIPS FILES ON SECONDARY TAPE IF NECESSARY
C
      CALL W1322(5,LFILE)
      NFILE=IFILE
      GO TO 602
  610 NFILE=0
C
C*******************************************************************
C*******************************************************************
C ************************************************************** ****8
C
C        CONTROLS NUMBER OF PASSES NEEDED BY NODAT
C
C*******************************************************************
C
  602 DO 630 IZ=1,NODAT
      CALL W1322(4,2)
C
C        READS 2ND PARAMETER CARD - NOSET
C
      READ(2,768)NOSET
  768 FORMAT(I5)
C
C*******************************************************************
```

```
C
C         CONTROLS NUMBER OF AREAS IN CURRENT PASS BY NOSET
C
C*********************************************************************
      DO 500 IBIG=1,NOSET
C
      IRECD=0
C
C         READS 3TH PARAMETER CARD - INFLNO,IH2O,IDAY,IMNTH,IYEAR
C
      READ(2,237)IFLNO,IH2O,IDAY,IMNTH,IYEAR
  237 FORMAT(5I5)
C
      IIN(1)=IFLNO
      IIN(2)=IH2O
      IIN(3)=IDAY
      IIN(4)=IMNTH
      IIN(5)=IYEAR
      DO 238 IA=6,9
  238 IIN(IA)=0
C
C         WRITES 3TH PARAMETER CARD ON 1ST RECORD ON SECONDARY TAPE
C         FOR THE NEW FILE
C
      CALL MGTAP(1,3,IIN,9,NO)
      NRCD=NRCD-1
      DO 222 JN=1,NRCD
  222 CALL MGTAP(0,2,IIN,MAX,NO)
C
C*********************************************************************
C
C         READS 4TH PARAMETER CARD -
C
      READ(2,100)NQUAD,IHSTA,IHEND,IX,IY,M,IH,IV,ICHAN
      WRITE(3,100)NQUAD,IHSTA,IHEND,IX,IY,M,IH,IV,ICHAN
```

```
  100 FORMAT(9I5)
C
C
C***********************************************************************
C
C          CONTROLS NUMBER OF TRAPEZOIDS IN AREA BY NQUAD
C***********************************************************************
C
      DO 200 KK=1,NQUAD
C
C          READS IN NQUAD GROUPS OF FOUR PTS. THAT DETERMINE
C          EACH TRAPEZOID THAT WILL COMPRISE THE IRREGULAR SHAPED
C          ARE PLUS AN ID NUMBER FOR EACH TRAPEZOID
C
      READ(2,101)(ID(K),K=1,5),(IPT(I),I=1,8)
      WRITE(3,101)(ID(K),K=1,5),(IPT(I),I=1,8)
  101 FORMAT(5I2,8I5)
C
C          SHIFTING OF COORD.'S DONE HERE IF NECESSARY
C
      IHSTA=IHSTA+IX
      IHEND=IHEND+IX
      DO 10 J=1,8,2
      JK=J+1
      IPT(J)=IPT(J)+IX
   10 IPT(JK)=IPT(JD)+IY
C
C          CHANGING ID NUMBER FROM INTEGER TO REAL
C
      DO 20 JJ=1,8
      PT(JJ)=FLOAT(IPT(JJ))
   20 CONTINUE
C
C          CHECKS FOR ''0'' DEMON.
C
```

```
      A=PT(5)-PT(3)
      IF(A)21,25,21
   25 A=A+1
   21 B=PT(1)-PT(7)
      IF(B)23,22,23
   22 B=B+1
C
C        CALCULATES THE Y INTERCEPTS AND SLOPES OF LINES THAT MAKE
C        UP THE SIDES OF THE TRAPEZOID
C
   23 E(1)=(PT(6)-PT(4))/A
      E(2)=-(E(1)*PT(3))+PT(4)
      E(3)=(PT(2)-PT(8))/B
      E(4)=-(E(3)*PT(1))+PT(2)
C
C        STORES ABOVE INTO QUAD
      DO 40 KL=6,9
      L=KL-5
   40 QUAD(KK,KL)=E(L)
C
C        STORES ID'S INTO QUAD
C
      DO 30 KJ=1,5
      DENT(KJ)=FLOAT(ID(KJ))
   30 QUAD(KK,KJ)=DENT(KJ)
C
C        STORES PTS. 2 AND 6 INTO QUAD (PTS. 2 AND 6 ARE USED TO
C        COMPLETE THE TRAPEZOID - TOP AND BOTTOM ,RESP.-
C
      QUAD(KK,10)=IPT(2)
      QUAD(KK,11)=IPT(6)
  200 CONTINUE
C
C**************************************************************************
C
```

```
      MAX=1800
      J=0
C
C        CLEARS DISPLAY UNIT OF ALL COMMANDS
C        READYS DISPLAY UNIT FOR START OF INPUT DATA
C
      CALL EXTIN
      CALL SOI
C
C*************************************************************************
C*************************************************************************
C
      DO 300 KK=1,NQUAD
C
C        BEGINS BACK THE NEEDED DATA FACTORS FOR EACH TRAPEZOID
C        PROGRAM WORKS WITH ONLY ONE TRAPEQOID AT ANY ONE TIME
C
      IVSTA=IFIX(QUAD(KK,10))
      IVEND=IFIX(QUAD(KK,11))
C
C        POSITIONS  AREA ON DISPLAY WITH ADJUSTMENTS MADE FOR IH,IV,
C        AND BLOW-UP FACTOR
      IHORZ=IH+IHSTA*M
      IVERT=IV+IVSTA*M
      CALL RANDM(IHORZ,IVERT)
C
C
C        CHECKS POINT IHSTA TO SEE IF FIRST PT. IS IN A ODD OR EVEN
C        POSITION IN INTERWEAVED ERTS DATA
C
      I1BIT=ISLA(IHSTA,15)
C
      NUMB=4*(IHEND-IHSTA+1)
      NB=4*((IHEND-IHSTA+1)/2)
      BNUMB=NB
```

```
      KBEGN=1+4*((IHSTA-1)/2)
C
   11 CALL MGTAP(0,2,IIN,MAX,NO)
      J=J+1
C
C        CHECKS TO SEE IF  THE Y COORD.(PT.2) HAS BEEN REACHED
C
      IF(J-IVSTA)11,15,15
C
   15 IF(NO)16,125,18
C
C        CONSIDERATION FOR A BAD READ CONDITION ON 1ST TAPE
C
   16 WRITE(3,104) J
  104 FORMAT('  BAD RECORD',I4)
      GO TO 11
C
C        CHECKS CHANNEL 4 FOR STARTING OF GOOD DATA
C
   18 ICHEK=4
    4 IF(IIN(ICHEK))2,1,1
    1 START=ICHEK
      GO TO 51
    2 ICHEK=ICHEK+4
      IF(ICHEK-1740)4,4,12
   12 WRITE(3,109)
  109 FORMAT('  ALL NEGATIVE')
      GO TO 16
C
C
C        COORNIATES THE X COMPONENT - FOR ERTSA
C
   51 IF(IWORD)62,62,63
   63 START=1+(IWORD-1)*4
   62 KBEGN=START+4*((IHSTA-1)/2)
```

```
   65 N=NO-START-27
      NB=BNUMB
      IF(IHEND-N)72,72,61
   61 WRITE(3,105)
  105 FORMAT('  IHEND WENT TOO FAR')
      GO TO 300
C
C         SPLITS ERTS WORD TO GET THE TWO DATA POINTS CONTAINED
C         IN ONE ERTS WORD
C
 72   CALL HALF(IIN(KBEGN),IOUT,NB)
      DO 75 I=1,NB
      IF(IOUT(I))73,75,75
   73 I=I+1
      GO TO 77
   75 CONTINUE
      I=1
   77 NB=NB-I+1
C
C         CHECKS FOR EVEN OR ODD POSITION
C
      IF(I1BIT)201,201,202
  201 JM=2
      NN=2
      GO TO 83
  202 JM=1
      NN=1
C
   83 ICONT=0
      KL=1
      LJ=4
      Y=FLOAT(J)
C
C*****************************************************************************
C        HERE THE JTH LINE (Y) AND ITH POSITION (X) ARE
```

```
C         CHECKED ON A POINT BY POINT BASES  IN THE AREA
C         DEFINE BY IHSTA,IHEND,PT.2, AND PT.6
C         ONLY POINTS LYING  IN THE AREA DEFINE BY THE TRAPEQOID
C         ARE KEPT, OTHER POINTS ARE ZEROED OUT
C*************************************************************************
C
      DO 155 I=IHSTA,IHEND
      X=FLOAT(I)
      IF(J-IVEND)19,299,299
   19 IF(J-IVSTA)41,32,32
   32 EQ2=QUAD(KK,6)*X+QUAD(KK,7)-Y
      IF(QUAD(KK,6))33,34,34
   33 IF(EQ2)35,35,41
   34 IF(EQ2)41,35,35
   35 IF(J-IVEND)36,41,41
   36 EQ4=QUAD(KK,8)*X+QUAD(KK,9)-Y
      IF(QUAD(KK,8))37,38,38
   37 IF(EQ4)41,39,39
   38 IF(EQ4)39,39,41
C
C         SAVE GOOD DATA
C
   39 DO 165 KI=KL,LJ
         ISAVE(KI)=IOUT(JM)
  165 JM=JM+2
      JM=JM-2
      GO TO 144
C
C         ZERO'S OUT UNWANTED DATA
C
   41 DO 166 KI=KL,LJ
  166  ISAVE(KI)=0
      JM=JM+6
C
  144 ICONT=ICONT+4
```

```
      KL=KL+4
      LJ=LJ+4
      GO TO(175,176),NN
  175 NN=2
      JM=JM-5
      GO TO 155
  176 NN=1
      JM=JM+1
  155 CONTINUE
C
C        WRITES ISAVE VECTOR CONTAINING DATA OF TRAPEQOID ON TO 2ND TAPE
C
      CALL MGTAP(1,3,ISAVE,NUMB,KACNB)
C
C
C        BLOWING - UP OF ISAVE VECTOR -IDSPY- FOR DIPLAYING
C
      NM=0
      DO 180 KM=ICHAN,NUMB,4
      DO 180 MK=1,M
      NM=NM+1
  180 IDSPY(NM)=ISAVE(KM)
C
C        DISPLAYS IDSPY VECTOR
C
      DO 190 NK=1,M
      CALL DISPY(IDSPY,NM)
  19/ CALL EOL
C
C        CHECKS TO SEE IF REACHED END OF SCREEN
C
      IF(J-2048)170,170,125
C
C        COUNTS NUMBER OF RECORDS THAT COMPRISE A FILE
C
```

```
  170 IRECD=IRECD+1
C
      GO TO 11
C
  299 J=J-1
C
C        DUE TO THE FACT THAT THE BASE OF ONE TRAPEQOID IS THE TOP
C        OF THE FOLLOWING ONE  A BACK-SPACEING OF ONE RECORD IS NEEDED
C        BACKSPACING ONE RECORD DONE HERE
C
      CALL MGTAP(0,7,ISAVE,NUMB,IEOF)
C
  300 CONTINUE
C
C*******************************************************************************
C*******************************************************************************
C        END OF FILE MARK COMMAND ON 2ND TAPE
      CALL MGTAP(1,8,ISAVE,NUMB,IEOF)
      NFILE=NFILE+1
C
C        SAVES IMPORTANT FACTS ON TEMP. DISK FILE
C
      WRITE(1'KAPPA)JTAPE,IRECD,NOSET,ID(1),ID(2),ID(3),IH20
C
      KKK=KKK+1
C
  500 CONTINUE
C
C*******************************************************************************
C*******************************************************************************
C
C        REWIND COMMAND FOR 1ST TAPE
C
      CALL MGTAP(0,5,ISAVE,NUMB,IEOF)
C
```

```
  630 CONTINUE
C*********************************************************************
C*********************************************************************
C*********************************************************************
C
C          WRITES FACTS STORED OUT ON TEMP. DISK FILE ON TO PRINTER
  125 KAPPA=1
      IF(KKK-1)131,640,640
  640 CONTINUE
      WRITE(3,877)
  877 FORMAT(1H1)
      DO 622 LL=1,KKK
      READ(1'KAPPA)JTAPE,IRECD,NOSET,ID(1),ID(I),ID(3),IH20
      WRITE (3,603) JTAPE,ID(1),ID(2),ID(3),IH20,NFILE,IRECD
  603 FORMAT(10X,'TAPE NUMBER IS',I5,'  AREA OF ID',5I2,'  IS IN FILE '
     1'NUMBER',I6,'  WITH',I6,  RECORDS')
C
  622 CONTINUE
C
C          COMMAND TO DISPLAY UNIT THAT ALL DATA HAS BEEN SENT
C
  131 CALL STOP
C
C          REWIND UNLOAD COMMAND TO 1ST TAPE
C
      CALL MGTAP (0,6,ISAVE,NUMB,KACNB)
C
      NFILE=NFILE+1
C
      CALL MGTAP(1,5,ISAVE,NUMB,KACNB)
C
C          UPDATES FILE COUNT ON 2ND TAPE
C          IFILE CHANGED
C
      WRITE(5)JTAPE,NFILE
```

```
C
C*******************************************************************************
C
      CALL MGTAP(1,5,ISAVE,MAX,NO)
      CALL EXIT
C
  600 WRITE(3,103)ITAPE
  103 FORMAT(21X,'WRONG TAPE -SHOULD BE TAPE NUMBER',I5)
      GO TO 131
      END
```

W1322

```
        ENT        W1322 (LUN,N)
W1322   DC         *-*           WHERE
        STX    1   XR1+1                LUN  = 4 OR 5
        LDX   I1   W1322                N    = + FILE MARK-1
        LD    I1   0                              1 RETURN
        S          C4                          IF LARGER SKIP
        STO        LUN                         THAT MANY FILE
        LD    I1   1                           MARKS
        MDX    1   2                         = 0 UNLOAD DRIVE
        STX    1   BACK+1                    = - NUMB OF RECORD
        BNP        STO                            TO SKIP
        S          C1
        BZ         XR1          RETURN IF ONLY 1 FILE
STO     STO        N
        CALL       FILE
        DC         LUN
        DC         N
XR1     LDX   L1   *-*
BACK    BSC   L    *-*
C4      DC         4
C1      DC         1
LUN     DC         *-*
N       DC         *-*
        END
```

FILE

```
      ENT       FILE (I,N)
FILE  DC        *-* WHERE
      STX    1  XR1+1         I= 0 OR 1 (MAG DRIVE)
      LDX   I1  FILE          N= + NUMB OF FILE MARKS
      LD    I1  0                0 UNLOAD
      A         READ             - NUMB OF RECORDS TO
      STO       CMND1              SKIP (ABSOLUTE VALUE)
      LD    I1  0             -------------------------
      A         UNLOD         - IF A FILE MARK IS      -
      STO       CMND2         - ENCOUNTERED DURING  A  -
      LD    I1  1             - RECORD SKIP IT IS      -
      STO       FILE          - COUNTED AS A RECORD.   -
      MDX    1  2             -------------------------
      STX    1  BACK+1
      BZ        UNLD
      BP        STO
      EOR       MASK          CONVERT NEG RECORD
      S         MASK          SKIP TO POS COUNT
STO   STO       LDXR1+1
LDXR1 LDX   L1  *-*
      CALL      P1053         TAKE EAC PRINTER
      DC        0             OFFLINE
      DC        LIST
CALL  CALL      P2401
CMND1 DC        *-*
      DC        LIST
      BSC       -Z
      MDX       CALL
      BZ        MODFY         EOF INCOUNTERED
      A         C3            IF END OF TAPE
      BZ        UNLD          UNLOAD DRIVE
      LD        FILE
      SKP       -             SKIP IF RECORD SKIP
      MDX       CALL
```

FILE CONTINUED

```
MODFY MDX    1 -1
      MDX      CALL
UNL   CALL     P1053      PUT EAC PRINTER
      DC       /0100      ONLINE
      DC       LIST
XR1   LDX   L1 *-*
BACK  BSC   L  *-*
UNLD  CALL     P2401
CMND2 DC       *-*
      DC       LIST
      MDX      UNL
READ  DC       /2000
UNLOD DC       /6000
MASK  DC       -1
C3    DC       3
LIST  DC       6
      BSS      6
      END
```

EXTIN

```
       ENT        EXTIN
EXTIN  DC         *-*
       CALL       WRITE        SEND
       DC         CODE
RETRN  BSC   I    EXTIN        RETURN
CODE   DC         /8000        CODE FOR EXTERNAL INITIAL
       END
```

WRITE

```
      ENT      WRITE       ENTER SUBROUTINE
WRITE DC       *-*         STORES VALUE OF RETRN-1
      STX   1  SAVE1+1     SAVE XR1
      LDX   I1 WRITE       LOAD ADDRESS OF VALUE
      LD    I1 0           TO BE WRITTEN INTO ACCUM.
      MDX   1  1           MODIFY RETURN ADDR BY 1
      STX   1  RETRN+1
      STO      DATA        AND STORE
BUSY  XIO      DSWO        TEST DO FOR BUSY STATE
      BOD      BUSY        LOOP IF BUSY
      XIO      WRIT        SEND OUTPUT TO DISPLAY
SAVE1 LDX   L1 *-*
RETRN BSC   L  *-*         RETURN
      BSS   E  0
DSWO  DC       0
      DC       /6701
WRIT  DC       AREA
      DC       /65C0
AREA  DC       /4002
      DC       126
DATA  DC       *-*
      END
```

SOI

```
       ENT      SOI
SOI    DC       *-*
       CALL     WRITE        SEND
       DC       START        CODE FOR START OF INPUT
RETRN  BSC   I  SOI          RETURN
START  DC       /8001
       END
```

RANDM

```
       ENT       RANDM
RANDM  DC        *-*
       STX     1 SAVE1+1
       LDX    I1 RANDM
       LD     I1 0            LOAD HORIZ POSITION IN ACC
       BN        VERTI        IF  -  CHECK VERT POSITION
       CMP       MAX          TEST HORIZ WITH MAX=2033
       MDX       VERTI        IF GREATER BRANCH TO VERTI
       NOP                    IF LESS BRANCH TO HORIZ
HORIZ  SRT       8            SAVE AND
       STO       POSIT+1      STORE 2ND POSITIONING WORD
       SLA       16           ZERO ACCUM.
       SLT       8            RECOVER AND
       STO       POSIT        STORE 1ST POSITIONING WORD
       LD        HOR          SEND THE
       STO       COMND        HORIZONTAL RANDOM COMMAND
BUSY1  XIO       DSWO         AND THE FIRST AND SECOND
       BOD       BUSY1        WORD OF THE RANDOM
       XIO       WRIT         POSITIONING FORMAT
VERTI  LD     I1 1            LOAD VERTI POSITION IN ACC
       BN        RETRN        AND PREFORM THE SAME TESTS
       CMP       MAX          AS FOR HORIZ, BUT RETURN
       MDX       RETRN        IF VERTI VALUE IS NOT RITE
       NOP
       SRT       8
       STO       POSIT+1
       SLA       16
       SLT       8
       STO       POSIT
       LD        VER
       STO       COMND
BUSY2  XIO       DSWO
       BOD       BUSY2
       XIO       WRIT
```

RANDM CONTINUED

```
RETRN MDX    1 2
      STX    1 BACK+1
SAVE1 LDX   L1 *-*
BACK  BSC   L  *-*
MAX   DC       2047
HOR   DC       /8008
VER   DC       /8009
      BSS   E  0
DSWO  DC       0
      DC       /6701
WRIT  DC       AREA
      DC       /65C0
AREA  DC       /4004
      DC       126
COMND DC       *-*
POSIT DC       *-*
      DC       *-*
      END
```

STOP

```
        ENT       STOP
STOP    DC        *-*
        CALL      WRITE
        DC        EOL
        BSC   I   STOP
EOL     DC        /8004
        END
```

```
      REAL MEAN(4),N(4)
      INTEGER TAPE
      DIMENSION ISAVE(4000)
      DIMENSION SUMX(4),SUMXX(4),SD(4)
      DIMENSION NFILE(32)
      DATA X1,X2/'STAN','DARD'/
      MAX=4000
      KONST=3
      IBACK=100
      READ(2,100) TAPE,IDRIV,NPPB,NUFIL
      WRITE(3,100)TAPE,IDRIV,NPPB,NUFIL
      READ(2,100) NFILE
      WRITE(3,100) NFILE
  100 FORMAT(16I5)
      READ(IDRIV) JTAPE,IFILE
      WRITE(3,1023)JTAPE,IFILE
 1023 FORMAT(1X,2I5)
      IF(TAPE-JTAPE)90,10,90
   10 IM=IDRIV-4
      DO 40 IN=1,NUFIL
      MI=IN+1
      CALL FLSRH(ISAVE,MAX,NFILE(IN),NFILE(MI),KONST,IDRIV,IBACK)
   11 CALL MGTAP(IM,1,ISAVE,MAX,NO)
      WRITE(3,120) (ISAVE(IB),IB=1,5)
  120 FORMAT(1H1,1X,'SCENE 1274 ',I6,'       DOVER        ',I6,
     1'  DATA FOR THE ',I6'  SITE 3    ',I3,2X,'MONTH OF 19',I2)
    3 ICONT=0
      DO 400 I=1,4
      MEAN(I)=0.
      N(I)=0.
      SUMX(I)=0.
      SUMXX(I)=0.
  400 CONTINUE
   26 CALL MGTAP(IM,1,ISAVE,MAX,NO)
```

```
      IF(NO)90,27,25
   25 L=1
      LL=2
      DO 200 J=1,NO,4
      IF(ISAVE(L)+ISAVE(LL))50,13,50
   50 JK=J
      DO 12 II=1,4
    6 ICONT=ICONT+1
      N(II)=N(II)+1.
      X=FLOAT(ISAVE(JK))
      SUMX(II)=SUMX(II)+X
      SUMXX(II)=SUMXX(II)+X*X
   12 JK=JK+1
   13 L=L+4
      LL=LL+4
  200 CONTINUE
      GO TO 26
   27 CALL MGTAP(IM,7,ISAVE,MAX,NO)
      WRITE(3,701)X1,X2
      WRITE(3,702)
  701 FORMAT(/,34X,2A4,6X,'NUM. OF PTS.')
  702 FORMAT(25X,'MEAN',5X,'DEVIATION',5X,'CONSIDERED')
      DO 201 IJ=1,4
      MEAN(IJ)=SUMX(IJ)/N(IJ)
      SD(IJ)=SUMXX(IJ)-(SUMX(IJ)*SUMX(IJ))/N(IJ)
      SD(IJ)=SQRT(SD(IJ)/(N(IJ)-1.))
      KN=IJ
      WRITE(3,703)KN,MEAN(KN),SD(KN),N(KN)
  201 CONTINUE
  703 FORMAT(10X,'CHANNEL',I3,2X,F7.2,3X,F8.3,6X,F9.0)
   40 CONTINUE
      GO TO 80
   90 WRITE(3,106) TAPE
  106 FORMAT(10X,'WRONG TAPE. SHOULD BE TAPE NUMBER',I3)
   80 CALL MGTAP(IM,6,ISAVE,MAX,NO)
      END
```

FLSRH

```
      SUBROUTINE FLSRH(ISAVE,MAX,NFILE,KFILE,KONST,IDRIV,IBACK)
      DIMENSION ISAVE(1)
      IM=IDRIV-4
      CALL MGTAP(IM,7,ISAVE,MAX,NO)
      ICHEK=NFILE-KFILE
      IF(ICHEK-NFILE)8,10,8
    8 IF(ICHEK)1,1,2
      ICHEK=KFILE-NFILE+1
      CALL W1322(IDRIV,ICHEK)
      GO TO 10
    2 IF(ICHEK-KONST)3,3,4
    3 IF(IBACK-NFILE)9,9,4
    9 DO 6 I=1,2
    6 CALL MGTAP(IM,7,ISAVE,MAX,NO)
      CALL MGTAP(IM,2,ISAVE,MAX,NO)
      IF(NO)3,7,3
    7 ICHEK=ICHEK-1
      IF(ICHEK)10,3,3
    4 CALL MGTAP(IM,5,ISAVE,MAX,NO)
      CALL W1322(IDRIV,2)
      IF(KFILE-1)10,10,5
    5 CALL W1322(IDRIV,KFILE)
   10 RETURN
      END
```

DESPY

```
C  THIS IS A PROGRAM THAT WILL DISPLAY DIGITAL DATA IN SECONDARY FORMAT
C  ON THE DICOMED DISPLAY
       INTEGER COR
       DIMENSION IVECT(6000),IDSAV(700),ID(26),IDD(256),MINMX(2)
      1,IDSA(700)
       DATA MINMX/' ','Z'/
       IMAX=6000
       COR=2
       LINE=3
C  NCHAN IS THE CHANNEL THAT IS TO BE DISPLAYED
C  MGIN T IS THE DRIVE ON WHICH THE INPUT TAPE IS LOCATED
C  NUMCH IS THE NUMBER OF CHANNELS ON THE DATA TAPE TO BE DISPLAYED
C  IMAGE WILL RESULT
C  IRCD1 IS THE FIRST RECORD TO BE DISPLAYED
C  IRCD IS THE NUMBER OF RECORDS TO BE DISPLAYED
C  INCRR - INCREMENT RECORDS
C  KSMP1 IS THE FIRST PIXEL ON THE SCAN LINE TO BE DISPLAYED
C  KSMP IS THE NUMBER OF PIXELS TO BE DISPLAYED
C  INCRS - INCREMENT SAMPLES WITHIN RECORDS
C  IVAL1 - MINIMUM DIGITAL VALUE EXPECTED
C  IVAL2 - MAXIMUM DIGITAL VALUE EXPECTED
C  INCRV - INCREMENT OF DIGITAL VALUES
       READ(2,1000)NCHAN,MGIN,NUMCH,IRCD1,IRCD,INCDR,KSMP1,KSMP,INCRS,
      1IVAL1,IVAL2,INCRV
       READ(2,103) ID
   103 FORMAT(26A1)
       DO 5 I=1,256
     5 IDD(I)=MINMX(1)
       DO 3 I=1,IVAL1
     3 IDD(I)=MINMX(1)
       DO 4 I=IVAL2,256
     4 IDD(I)=MINMX(2)
  1000 FORMAT(16I5)
C  INITIALIZE SCREEN
```

DESPY CONTINUED

```
      J=0
      K=IVAL1-1
      DO 1 I=IVAL1,IVAL2,INCRV
      J=J+1
      DO 1 L=1,INCRV
      K=K+1
    1 IDD(K)=ID(J)
      DO 2 I=IVAL1,IVAL2,INCRV
      II=I+INCRV-1
    2 WRITE(3,101) I,II,IDD(I)
  101 FORMAT(1X,2I8,2X,A1)
      WRITE(3,102)
  102 FORMAT(1H1)
      CALL MGTAP(MGIN,1,IVECT,IMAX,NO)
C  CHECK FOR AN ERROR
      IF(NO)20,20,40
   20 WRITE(LINE,2000)MGIN,NO
 2000 FORMAT(1X,'BAD READ ON DRIVE ',I3,2X,'ERRCODE',1X,I5,//)
      CALL STOP
      CALL RWIND(MGIN)
      CALL EXIT
   40 CONTINUE
      DO 50 I=1,NUMCH
      IA=I+2
      IF(IVECT(IA)-NCHAN)50,70,50
C  PAGE I CONTINUE PROGRAM DESPY
   50 CONTINUE
      WRITE(LINE,2010)
 2010 FORMAT(1X,'COULD NOT FIND CHANNEL POSITION AS SPECIFIED ON TAPE,C
     *HECK AND MAKE SURE THAT YOU HAVE RIGHT TAPE-CALL EXIT',//)
      CALL EXIT
C  THIS IS THE CHANNEL POSITION OF THE PIXEL
   70 IPOSI=I+24
      MM=0
      MMM=1
```

```
      KSMP2=KSMP1+KSMP-1
   85 CALL MGTAP(MGIN,1,IVECT,IMAX,NO)
      IF(NO)20,20,90
C  THIS IS IF WE GOT A GOOD READ
C  SKIP TAPE RECORDS UNTIL WE GET TO IRCD1
   90 IF(IVECT(1)-IRCD1)85,110,85
  110 IF(IVECT(2))120,130,120
  120 IF(IVECT(2)-1)125,130,125
  125 WRITE(LINE,2030)
 2030 FORMAT(1X,'TAPE RECORDS ARE NOT IN CORRECT ORDER-CALL EXIT',//)
      CALL EXIT
  130 ITHIS=IVECT(1)
      IVCTE=IRCD1+IRCD
      MM=MM+1
      IDISE=0
  142 IDISS=IDISE
      CALL SELET(IVECT(IPOSI),IVECT,NUMCH,NO)
      CALL SPLIT(IVECT,IDSAV(IDISS),NO)
      IDISE=IDISS+NO-2
  145 CALL MGTAP(MGIN,1,IVECT,IMAX,NO)
      IF(NO)20,20,150
  150 IF(IVECT(1))160,145,160
  160 IF(IVECT(1)-ITHIS)170,142,170
  170 IF(MM-MMM)175,180,175
  180 MMM=MMM+INCDR
      DO 155 KK=KSMP1,KSMP2,INCRS
      KKK=701-KK
      JJ=IDSAV(KKK)+1
  155 IDSA(KK)=IDD(JJ)
      WRITE(3,100)MM,(IDSA(KK),KK=KSMP1,KSMP2,INCRS)
  175 IF(IVECT(1)-IVCTE)130,130,260
  100 FORMAT(1X,I5,2X,124A1)
  260 CALL SKIP(3,1)
      CALL EXIT
      END
```

SELET

```
***** **** *$ CALL SELET(ID,IOUT,NV,NCONT)
      ENT       SELET
$WK4  EQU       54
SELET DC        *-*
      CALL      QZSAV
      MDM       $WK4,+4
      LDX    I1 SELET
      LD      1 0
      STO       LDXR1+1
      LD      1 1
      STO       LDXR2+1
      LD     I1 2
      M         KMIN1
      SLT       16
      STO       NV1+1
      STO       NV2+1
      LD      1 3
      STO       ADRS+1
      LD     I1 3
      STO       LDXR3+1
LDXR1 LDX    L1 *-*
LDXR2 LDX    L2 *-*
LDXR3 LDX    L3 *-*
      LD        K0
      STO    I  ADRS+1
LOOP  LD      1 0
      STO     2 0
ADRS  MDX    L  *-*,+1
NV1   MDX    L1 *-*
      MDX     2 -1
NV2   MDX    L3 *-*
      MDX       LOOP
      CALL      QZEXT
KMIN1 DC        -1
      END
```

```
      SUBROUTINE DISCM
C       MULTIPLE GROUP DISCRIMINANT ANALYSIS. A COOLEY-LOHNES PROGRAM.
C       THIS PROGRAM COMPUTES DISCRIMINANT FUNCTIONS, THEIR CANONICAL
C     CORRELATIONS WITH GROUP MEMBERSHIP DUMMY VARIATES, F-RATIOS FOR
C     THESE, AND CENTROIDS OF GROUPS IN THE STANDARDIZED DISCRIMINANT
C     FUNCTIONS SPACE.  COEFFICIENTS FOR COMPUTING STANDARDIZED
C     DISCRIMINANT FUNCTIONS SCORES FROM DEVIATION TEST SCORES ARE
C     PUNCHED OUT.
C
C       REQUIRED SUBROUTINES ARE DIRNM AND HOW.
C
C       INPUT
C
C     1) FIRST TEN CARDS OF DATA DECK CONTAIN A TEXT DESCRIBING THE
C     JOB, WHICH WILL BE REPRODUCED ON THE OUTPUT.  DO NOT USE COLUMN 1.
C     2) CONTROL CARD (CARD11)
C       COLS 1-2  M=NUMBER OF VARIABLES
C       COLS 3-5  KG=NUMBER OF GROUPS
C       COLS 6-10 N=NUMBER OF SUBJECTS
C       COLS 11-12 KC=NUMBER OF CONTROL VARIABLES PREVIOUSLY
C       PARTIALED OUT BY COVAR (THIS VALUE WILL BE A
C       ZERO IF INPUT MATRICES COME FROM MANOVA).
C       3)T MATRIX (TOTAL SAMPLE DEVIATION SSCP, AS PUNCHED BY MANOVA
C       OR COVAR).
C     4) W MATRIX (POOLED WITHIN-GROUPS DEVIATION SSCP MATRIX, AS PUNCHE  D
C       BY MANOVA OR COVAR).
C     5) GROUP MEANS (AS PUNCHED BY MANOVA OR COVAR).
C     6) GRAND MEANS (AS PUNCHED BY MANOVA).
C
      DIMENSION A(20,20),B(20,20),C(20,20),T(20),U(20),V(20),
     * W(20),X(20),Y(20),Z(20),TIT(10,20),D(20,20),E(20,20),IWS(20),
     * ISCN(20),NV(20)
      COMMON M,KG,N,KC,TIT,NTITLE,IWS,ISCN,NV
C
```

```
    1 WRITE (6,2)
    2 FORMAT(65H1MULTIPLE GROUP DISCRIMINANT ANALYSIS.  A COOLEY-LOHNES
     2PROGRAM.      )
 2301 FORMAT(162(10A4))
      DO 3 I = 1,NTITLE
    3 WRITE(6,4)(TIT(I,J),J=1,20)
      WRITE(6,2302)(NV(K),K=1,M)
 2302 FORMAT(///1X,'FOR THIS ANALYSIS - - THE FOLLOWING DATA WERE USED '
     1//20X,'BANDS',5I5)
      DO 2303 I=1,KG
 2303 WRITE(6,2304)ISCN(I),IWS(I)
 2304 FORMAT(1X,'ERTS SCENE',I5,'   - - WATERSHED',I5)
      WRITE(6,2305)
 2305 FORMAT(////)
    4 FORMAT(20A4)
    9 FORMAT (I2, I3, I5, I2)
    5 FORMAT (10X,  5E14.7)
      DO 6 J=1,M
      READ(3,2301) (C(J,K),K=J,M)
    6 CONTINUE
      REWIND 3
      DO 7  J=1,M
      READ(4,2301)(B(J,K),K=J,M)
    7 CONTINUE
      REWIND 4
      DO 8  J=1,M
      DO 8  K=J,M
      C(K,J)=C(J,K)
    8 B(K,J)=B(J,K)
      DO 15 J=1,M
      DO 15 K=1,M
   15 A(J,K)=C(J,K) - B(J,K)
C     A NOW CONTAINS THE A MATRIX (AMONG-GROUPS DEVIATION SSCP MATRIX).
C     B CONTAINS THE W MATRIX (WITHIN-GROUPS DEVIATION SSCP MATRIX).
      IF (M-KG) 10,11,11
```


C-2

```
   10 MD=M
      GO TO 12
   11 MD=KG-1
C
   12 CALL DIRNM (A, M, B, D, T, MD)
C   ROOTS OF W INVERSE * A ARE IN T AND COLUMN EIGENVECTORS ARE IN D.
C
      EM=M
      EKG=KG
      EN=N
      EKC=KC
      XL=1.0
      TRACE=0.0
      DO 13 J=1,MD
      U(J)=T(J)/(1.0+T(J))
      V(J)=SQRT(U(J))
      W(J)=1.0/(1.0+T(J))
      XL=XL*W(J)
   13 TRACE=TRACE+T(J)
      D2=(EN-1.-EKG*EM)*TRACE
      DO 14 J=1,MD
   14 Z(J)=100.0*(T(J)/TRACE)
      IF (M-2) 16,16, 17
   16 IF (KG-3) 18,18, 17
   18 YL=XL
      F1=2.0
      F2=EN-3.0-EKC
      GO TO 19
   17 SL=SQRT (((EM*EM)*((EKG-1.0)**2)-4.0)/((EM*EM)+
     2  ((EKG-1.0)**2)-5.0))
      YL=XL**(1.0/SL)
      PL=(EN-1.0-EKC)-((EM+EKG)/2.0)
      QL=  - ((EM * (EKG-1.0))-2.0)/4.0
      RL=(EM*(EKG-1.0))/2.0
      F1=2.0*RL
```

```
      F2=(PL*SL)+(2.0*QL)
   19 N1=F1
      N2=F2
      F=((1.0-YL)/YL)*(F2/F1)
      YL=1.0-XL
      WRITE (6,201)XL,YL
  201 FORMAT('OWILKS LAMBDA = ',F5.4,'   GENERALIZED CORRELATION RATIO,
     CETA SQUARE = ',F5.4)
      WRITE(6,20) F
   20 FORMAT(45HOF-RATIO FOR H2,OVERALL DISCRIMINATION,=     F9.2)
      WRITE(6,21)    N1,  N2
   21 FORMAT(8HONDF1 = I3,  12H AND NDF2 = I6)
      J=MD
      X(J+1)=1.0
   22 X(J)=X(J+1)*W(J)
      J=J-1
      IF(J) 23,23,22
   23 DO 24 J=1,MD
   24 Y(J)= - PL * ALOG(X(J))
      WRITE(6,1002)TRACE,D2
 1002 FORMAT('OTRACE OF W-INVERSE*A= ',F10.5//,' GENERALIZED MAHANANOBIS
     1 D-SQUARE = ',F15.5)
      WRITE(6,25)
   25 FORMAT(48HOCHI-SQUARE TESTS WITH SUCCESSIVE ROOTS REMOVED   )
      WRITE(6,261)
  261 FORMAT(1H0,20X,22H(ETA)     (ETA SQUARE))
      WRITE(6,26)
   26 FORMAT('OROOTS REMOVED   CANONICAL R   R SQUARED    EIGENVALUE
     1CHI-SQUARE    N.D.F.    LAMBDA  PERCENT TRACE ')
      DO 27 J=1,MD
      JT=J-1
      NDF=(M-JT)*(KG-JT-1.0)
   27 WRITE(6,28)JT,V(J),U(J),T(J),Y(J), NDF, X(J),Z(J)
   28 FORMAT(6X,I4,9X,2(F6.3,8X),F9.3,5X,F10.0,4X,I5,2X,F9.2,F8.2)
C
```

```
      DO 29 J=1,MD
      DO 29 K=1,M
      A(J,K)=0.0
      DO 29 L=1,M
   29 A(J,K)=A(J,K)+D(L,J)*(C(L,K)/(EN-1.0))
      DO 30 J=1,MD
      DO 30 K=1,MD
      B(J,K)=0.0
      DO 30 L=1,M
   30 B(J,K)=B(J,K)+A(J,L)*D(L,K)
      DO 31 J=1,M
      DO 31 K=1,MD
   31 D(J,K)=D(J,K)*(1.0/SQRT(B(K,K)))
      WRITE(6,32)
      WRITE(7,32)
   32 FORMAT(25H0ROW COEFFICIENTS VECTORS    )
      DO 33 J=1,MD
      WRITE(6,49)     J,   (D(K,J),    K=1,M)
   33 WRITE(7,49)      J,    (D(K,J)  ,  K=1,M)
   49 FORMAT(5H D F  I3,2X,5E14.7 / (10X,5E14.7))
      DO 34 J=1,M
   34 Z(J)=SQRT(C(J,J) / (EN-1.0))
C     TOTAL SAMPLE STANDARD DEVIATIONS ARE NOW IN Z.
      DO 35 J=1,M
      DO 35 K=1,M
   35 C(J,K)=C(J,K) / (EN*Z(J)*Z(K))
C     TOTAL SAMPLE CORRELATION MATRIX IS NOW IN C.
      DO 36 J=1,M
      DO 36 K=1,MD
   36 B(J,K)=D(J,K)*Z(J)
      DO 37 J=1,M
      DO 37 K=1,MD
      A(J,K)=0.0
      DO 37 L=1,M
   37 A(J,K)=A(J,K)+C(J,L)*B(L,K)
```

```
      WRITE(6,38)
   38 FORMAT(42H0FACTOR PATTERN FOR DISCRIMINANT FUNCTIONS     )
      DO 39 J=1,M
   39 WRITE(6,40) J,(A(J,K), K=1,MD)
   40 FORMAT(5H0TEST I4,10(3X,F7.3)/(9X,10(3X,F7.3)))
      DO 41 J=1,M
      T(J)=0.0
      DO 41 K=1,MD
   41 T(J)=T(J)+A(J,K)*A(J,K)
      WRITE(6,42)
   42 FORMAT(19H0COMMUNALITITES FOR   I5,21H DISCRIMINANT FACTORS    )
      WRITE(6,43)       (J,   T(J),   J=1,M)
   43 FORMAT(1H0,10(2X, I3, F7.3))
      DO 44 J=1,MD
      T(J)=0.0
      DO 44 K=1,M
   44 T(J)=T(J)+A(K,J)*A(K,J)
      WRITE(6,45)
   45 FORMAT(53H0PERCENTAGE OF TRACE OF R ACCOUNTED FOR BY EACH ROOT  )
      DO 46 J=1,MD
   46 T(J)=100.0*(T(J) / EM)
      WRITE(6,43)      (J,  T(J),  J=1,MD)
C
      KGT=KG+1
      DO 47 J=1,KGT
   47 READ(1,2301)(A(J,K),K=1,M)
      REWIND 1
C     READS GROUP MEAN VECTORS AND GRAND MEAN VECTOR INTO COLUMNS OF A.
C     COLUMN KGT CONTAINS THE GRAND MEANS.
      DO 48 J=1,KG
      DO 51 K=1,MD
      T(K)=0.0
      DO 51 L=1,M
   51 T(K)=T(K)+(A(J,L) - A(KGT,L)) * D(L,K)
      WRITE(6,50)      J,  MD
```

```
   50 FORMAT(20HOCENTROID FOR GROUP   I4,4H IN I4,32H DIMENSIONAL DISCRI
     2MINANT SPACE      )
   48 WRITE(6,43)        (K,    T(K),    K=1,MD)
      NE=1
      DO 1000 K1=1,KG
      DO 1001 J=1,M
 1001 READ(8,2301)(A(J,K),K=J,M)
      DO 101 J=1,M
      DO 101 K=1,M
  101 A(K,J)=A(J,K)
      DO 104 I1=1,MD
      DO 103 I2=1,M
      E(I1,I2)=0.0
      DO 102 I3=1,M
  102 E(I1,I2)=E(I1,I2)+(D(I3,I1)*A(I3,I2))
  103 CONTINUE
  104 CONTINUE
      DO 107 I1=1,MD
      DO 106 I2=1,MD
      A(I1,I2)=0.0
      DO 105 I3=1,M
  105 A(I1,I2)=A(I1,I2)+(E(I1,I3)*D(I3,I2))
  106 CONTINUE
  107 CONTINUE
      WRITE(6,2012)K1,IWS(K1)
 2012 FORMAT(/////1X,'DISPERSION IN REDUCED SPARE FOR GROUP ',I2,
     1'  WATERSHED ',I5)
      DO 2013 I1=1,MD
      WRITE(6,108)(A(I1,I2),I2=1,MD)
  108 FORMAT(10X,8(E14.7,2X))
 2013 CONTINUE
 1000 CONTINUE
      REWIND 8
      RETURN
      END
```

DIRNM

```
      SUBROUTINE DIRNM (A,M,B,X,XL,LVECT)
C     SUBROUTINE DIRNM, DIAGONALIZATION OF A REAL NON-SYMMETRIC MATRIX
C     OF THE FORM B-INVERSE*A. CODED BY P. R. LOHNES, U. N. H.
C
C     A, M, B, X, AND XL ARE DUMMY NAMES AND MAY BE CHANGED IN THE
C     CALLING STATEMENT.
C     A AND B ARE M BY M INPUT MATRICES. UPON RETURN VECTOR XL CONTAINS
C     THE EIGENVALUES OF B-1*A, AND MATRIX X CONTAINS THE EIGENVECTORS
C     IN ITS COLUMNS.  SUBROUTINE HOW PACKAGE IS REQUIRED.
C
C     LVECT SPECIFIES THE NUMBER OF EIGENVECTORS TO BE RETURNED.
C
C
      DIMENSION A(20,20),B(20,20),X(20,20),XL(20),DUM1(20),DUM2(20)
     1,DUM3(20),DUM4(20),E(20)
C
      CALL HOW (M,20,M,B,XL,X,DUM1,DUM2,DUM3,DUM4)
C
      DO 13 I=1,M
      DIAG=SQRT(ABS(XL(I)))
      DO 13 J=1,M
   13 B(J,I)=X(J,I)*DIAG
   16 DO 1 I=1,M
    1 XL(I)=1.0/SQRT(ABS(XL(I)))
      DO 2 I=1,M
      DO 2 J=1,M
    2 B(I,J)=X(I,J)*XL(J)
      DO 3 I=1,M
      DO 3 J=1,M
      X(I,J)=0.0
      DO 3 K=1,M
    3 X(I,J)=X(I,J)+B(K,I)*A(K,J)
      DO 4 I=1,M
      DO 4 J=1,M
```

DIRNM CONTINUED

```
      A(I,J)=0.0
      DO 4 K=1,M
    4 A(I,J)=A(I,J)+X(I,K)*B(K,J)
C     A NOW CONTAINS BPRIME * A*B OF THE NOTES.
C
C
      CALL HOW(M,20,LVECT,A,XL,X,DUM1,DUM2,DUM3,DUM4)
C
      DO 6 I=1,M
      DO 6 J=1,M
      A(I,J)=0.0
      DO 6 K=1,M
    6 A(I,J)=A(I,J)+B(I,K)*X(K,J)
      DO 9 I=1,M
      SUMV=0.0
      DO 7 J=1,M
    7 SUMV=SUMV+(A(J,I)**2)
      DEN=SQRT (SUMV)
      DO 8 J=1,M
    8 X(J,I)=A(J,I) /DEN
    9 CONTINUE
C
C     COLUMNS OF X(I,J) ARE NOW NORMALIZED.
C
      RETURN
      END
```

```
      SUBROUTINE HOW(MVAR,MDIM,NVECT,R,E,V,A,B,C,D)
C     EIGENVALUES AND EIGENVECTORS OF A SYMMETRIC MATRIX, ALGORITHM
C     BY HOUSEHOLDER,ORTEGA,AND WILKINSON.  ORIGINAL PROGRAM BY
C     DAVID W. MATULA UNDER THE DIRECTION OF WILLIAM MEREDITH,UNIVERSITY
C     OF CALIFORNIA, BERKELEY,1962.
C     MODIFIED BY P. R. LOHNES, PROJECT TALENT, 1966.
C
C     M IS THE ORDER OF THE INPUT MATRIX,R.
C     MD IS THE DIMENSIONED SIZE OF R IN THE MAIN PROGRAM.
C     NV IS THE NUMBER OF EIGENVECTORS TO BE COMPUTED.
C      E IS THE VECTOR IN WHICH THE EIGENVALUES ARE RETURNED.
C      V IS THE MATRIX IN WHICH THE EIGENVECTORS ARE RETURNED.
C     THE EIGENVECTORS ARE STORED AS COLUMNS IN V.
C     A,B,C,AND D ARE WORKSPACE VECTORS.
C
      DIMENSION R(1),E(1),V(1),A(1),B(1),C(1),D(1)
C
      M=MVAR
      MD=MDIM
      NV=NVECT
      IF(M-1)100,97,96
   96 M1=M-1
C      TRI-DIAGONALIZE THE MATRIX.
      M2=M1*MD+M
      M3=M2-MD
      M4=MD+1
      L=0
      DO 1 I=1,M2,M4
      L=L+1
    1 A(L)=R(I)
      B(1)=0.0
      IF(M-2)13,2,3
    3 KK=0
      DO 15 K=2,M1
```

```
      KL=KK+K
      KU=KK+M
      KJ=K+1
      SUM=0.0
      DO 4 J=KL,KU
    4 SUM=SUM+R(J)**2
      S=SQRT(SUM)
      Z=R(KL)
      B(K)=SIGN(S,-Z)
      S=1.0/S
      C(K)=SQRT(ABS  (Z) * S + 1.0)
      X=SIGN(S / C(K), Z)
      R(KL)=C(K)
      DO 5 I=KJ,M
      JJ=I+KK
      C(I)=X*R(JJ)
    5 R(JJ)=C(I)
      DO 8 J=K,M
      JJ=J+1
      D(J)=0.0
      L=KK+J
      DO 6 I=K,J
      L=L+MD
    6 D(J)=D(J)+R(L)*C(I)
      IF(JJ-M) 7,7,9
    7 DO 8 I=JJ,M
      L=L+1
    8 D(J)=D(J)+R(L)*C(I)
    9 X=0.0
      DO 10 J=K,M
   10 X=X+C(J)*D(J)
      X=.50*X
      DO 11 I=K,M
   11 D(I)=X*C(I)-D(I)
      LL=KK
```

```
      KK=KK+MD
      DO 15 I=K,M
      LL=LL+MD
      DO 15 J=I,M
      L=LL+J
   15 R(L)=R(L)+D(I)*C(J)+D(J)*C(I)
      L=1
      DO 12 I=1,M
      X=A(I)
      A(I)=R(L)
      R(L)=X
   12 L=L+M4
    2 B(M)=R(M3)
C     COMPUTE EIGENVALUES.
   13 BD=ABS(A(1))
      DO 14 I=2,M
      IF (BD-(ABS(A(I))+B(I)**2))130,14,14
  130 BD=ABS(A(I))+B(I)**2
   14 CONTINUE
      BD=BD+1.0
      DO 16 I=1,M
      A(I)=A(I)/BD
      B(I)=B(I)/BD
      D(I)=1.0
   16 E(I)=-1.0
      DO 37 K=1,M
   17 IF (ABS(D(K))-ABS(E(K)))101,101,105
  101 AMAX1= ABS(E(K))
      GO TO 110
  105 AMAX1= ABS(D(K))
  110 IF (AMAX1-1.E-9) 115,120,120
  115 AMAX1 = 1.E-9
  120 CONTINUE
      IF ((D(K)-E(K))/AMAX1-1.E-6) 37,37,18
   18 X=(D(K)+E(K))*.50
```

```
      IS2=1
      S2=IS2
      C(1)=A(1)-X
      IF(C(1))19,20,20
   19 IS1=-1
      S1=IS1
      N=0
      GO TO 21
   20 IS1=1
      S1=IS1
      N=1
   21 DO 31 I=2,M
      IF(B(I))22,26,22
   22 IF(B(I-1))23,27,23
   23 IF(ABS(C(I-1))+ABS(C(I-2))-1.0E-15)24,25,25
   24 C(I-1)=C(I-1)*1.0E15
      C(I-2)=C(I-2)*1.0E15
   25 C(I) = (A(I)-X)*C(I-1)-B(I)**2 * C(I-2)
      GO TO 28
   26 C(I) = (A(I)-X) * SIGN (1.0, S1)
      GO TO 28
   27 C(I) = (A(I)-X) * C(I-1) - SIGN (B(I)**2, S2)
   28 S2 = S1
      IS2=S2
      IF (C(I))   29,  30,  29
   29 S1 = SIGN (S1,C(I))
      IS1=S1
      IF (IS2+IS1)   30,  31,  30
   30 N = N + 1
   31 CONTINUE
      N = M - N
      IF (N - K)  34,  32,  32
   32 DO 33  J = K, N
   33 D(J) = X
   34 N = N + 1
```

HOW CONTINUED

```
      IF ( M - N)    17,  35,  35
   35 DO 36  J = N, M
      IF (X - E(J))   17,  17,  36
   36 E(J) = X
      GO TO 17
   37 CONTINUE
      DO 38  I = 1, M
      A(I) = A(I) * BD
      B(I) = B(I) * BD
   38 C(I) = (D(I) + E(I)) * BD * .50
      M1 = M
      K = 1
   39 I = 1
   40 DO 43  J = 1, M1
      IF (I - J)  41,  43,  41
   41 IF (C(I) -C(J))   43,  43,  42
   42 I = J
      GO TO 40
   43 CONTINUE
      E(K) = C(I)
      K = K + 1
      M1 = M1 - 1
      IF (I - M1 - 1)  44,  46,  46
   44 DO 45  M2 = 1, M1
   45 C(M2) = C(M2+1)
   46 IF (M1 - 1)  47,  47,  39
   47 E(K) = C(1)
      IF (ISIGN  (1, NV))   79,  76,  76
   76 DO 77  I = 1, M
   77 C(I) = E(I)
      J = M
      DO 78  I = 1, M
      E(I) = C(J)
   78 J = J - 1
   79 CONTINUE
```

```
C
C     DECIDE WHETHER TO COMPUTE EIGENVECTORS, AND IF SO, HOW MANY
C
      IF (NV)    48,  99,  48
   48 KX = IABS(NV)
      J = 1
      DO 98  INV = 1,KX
      X = A(1) - E(INV)
      Y = B(2)
      M1 = M - 1
      DO 54  I = 1, M1
      IJ = J + I - 1
      IF (ABS (X) - ABS (B(I+1)))   49,  51,  53
   49 C(I) = B(I+1)
      D(I) = A(I+1) - E(INV)
      V(IJ) = B(I+2)
      Z = -X / C(I)
      X = Z * D(I) + Y
      IF (M1 - I)   50, 54,  50
   50 Y = Z * V(IJ)
      GO TO 54
   51 IF (X)  53,  52,  53
   52 X = 1.0E-10
   53 C(I) = X
      D(I) = Y
      V(IJ) = 0.0
      X = A(I+1) - (B(I+1) / X * Y + E(INV))
      Y = B(I+2)
   54 CONTINUE
      MJ = M + J - 1
      IF (X)   56,  60,  56
   56 V(MJ) = 1.0 / X
   57 I = M1
      IJ = J + I - 1
      V(IJ) = (1.0 - D(I) * V(MJ))/ C(I)
```

```
      X = V(MJ)**2 + V(IJ)**2
   58 I = I - 1
      IJ = J + I - 1
      IF (I)   59,  61,  59
   59 V(IJ) = (1.0 - (D(I) *  V(IJ+1) + V(IJ) * V(IJ+2))) / C(I)
      X = X + V(IJ)**2
      GO TO 58
   60 V(MJ) = 1.0E10
      GO TO 57
   61 X = SQRT(X)
      DO 62  I = 1, M
      IJ = J + I - 1
   62 V(IJ) = V(IJ) / X
      J1 = M1 * MD - MD
      K = M
      GO TO 66
   63 K = K - 1
      J1 = J1 - MD
      Y = 0.0
      DO 64   I = K, M
      IJ = J + I - 1
      L = J1 + I
   64 Y = Y + V(IJ) * R(L)
      DO 65   I = K, M
      IJ = J + I - 1
      L = J1 + I
   65 V(IJ) = V(IJ) - Y * R(L)
   66 IF (J1)   63,  67,  63
   67 NPLUS = 0
      NMIN = 0
      DO 70   I = 1, M
      IJ = J + I - 1
      IF (V(IJ))   68,  69,  69
   68 NMIN = NMIN + 1
      GO TO 70
```

```
   69 NPLUS = NPLUS + 1
   70 CONTINUE
      IF (NPLUS - NMIN)   71,  73,  73
   71 DO 72   I = 1, M
      IJ = J + I - 1
   72 V(IJ) = -V(IJ)
   73 CONTINUE
   98 J = J + MD
C     RESTORE THE INPUT MATRIX.
   99 MD1 = MD + 1
      JJ = MD1
      M1 = M * MD
      DO 75   I = 2, M1, MD1
      K = I
      DO 74   J = JJ,  M1,  MD
      R(K) = R(J)
   74 K = K + 1
   75 JJ = JJ + MD1
      GO TO 100
   97 E(1) = R(1)
      V(1) = 1.0
  100 RETURN
      END
```

MANOVA

```
C      MULTIVARIATE ANALYSIS OF VARIANCE.  A COOLEY-LOHNES ROUTINE.
C
C      THIS PROGRAM COMPUTES MANOVA TESTS OF H1(EQUALITY OF DISPERSION
C      AND H2 (EQUALITY OF CENTROIDS), UNIVARIATE F-RATIOS FOR MEANS,
C      SELECTED SAMPLE STATISTICS, AND THE W (POOLED WITHIN-GROUP SSCP)
C      AND T(TOTAL SAMPLE SSCP) MATRICES REQUIRED FOR THE DISCRIMINANT
C      ANALYSIS PROGRAM.  THESE MATRICES ARE PUNCHED IN UPPER-TRIANGULAR
C      FORM.  THE PROGRAM WILL PROCESS UP TO 50 VARIABLES AND ANY NUMBER
C      OF GROUPS.
C
C      INPUT
C
C      1)FIRST TEN CARDS OF THE DATA DECK DESCRIBE THE PROBLEM IN A TEXT
C      WHICH WILL BE REPRODUCED ON THE OUTPUT.  DO NOT USE COLUMN 1.
C      2) CONTROL CARD(CARD 11)
C      COLS 1-2 M=NUMBER OF VARIABLES
C      COLS 3-5 KG=NUMBER OF GROUPS
C      3)FORMAT CARD(CARD 12)
C      4)EACH GROUP OF SCORE CARDS IS PRECEDED BY A CARD GIVING
C      NG=NUMBER OF SUBJECTS IN THE GROUP(COLS 1-5).
C      THUS, SUBJECTS MUST BE SORTED INTO GROUPS AND THE GROUPS COUNTED
C      BEFORE MANOVA CAN BE RUN.
C
C      PUNCHED OUTPUT IS ALL TO FORMAT(10X,5E14.7 /(10X, 5E14.7)),AND IS
C
C      1)GROUP MEANS, FOLLOWED BY GRAND MEANS.
C      2)T MATRIX(TOTAL SAMPLE DEVIATION SSCP MATRIX)
C      3)W MATRIX(POOLED WITHIN-GROUPS DEVIATION SSCP MATRIX)
C      4)D INVERSE(INVERSE OF POOLED-SAMPLES DISPERSION ESTIMATE)
C
C      SUBROUTINE MATINV IS REQUIRED.
C
C
       DIMENSION TIT(10,20),A(20,20),B(20,20),C(20,20),
```

```
     *T(20),U(20),W(20),X(20),D(20,20),NV(20),
     *IWS(20),ISCN(20),SDA(4,4),SM(4),Y(3)
      COMMON M,KG,N,KC,TIT,NTITLE,IWS,ISCN,NV
      READ(5,1121)IGROUP
 1121 FORMAT(I2)
C
      DO 1122 I=1,IGROUP
      READ(5,1101)ISN,ISHD,ITIL,NG
 1101 FORMAT(6X,I5,T19,I5,T31,I5,T42,I8)
      Y(1)=ISN
      Y(2)=ISHD
      Y(3)=NG
      WRITE(2,102)Y
      DO 1123 J=1,4
      READ(5,1102)(SDA(J,K),K=1,4)
      WRITE(2,102)(SDA(J,K),K=1,4)
 1123 CONTINUE
      READ(5,1102)(SM(K),K=1,4)
      WRITE(2,102)(SM(K),K=1,4)
 1122 CONTINUE
C
      REWIND 2
C
    1 WRITE(6,2)
    2 FORMAT(33H1MANOVA. A COOLEY-LOHNES PROGRAM    )
      READ(5,1001,END=53)NTITLE
      DO 3 J=1,NTITLE
      READ(5,4)(TIT(J,K),K=1,20)
    3 WRITE(6,4)(TIT(J,K),K=1,20)
    4 FORMAT(20A4)
      READ(5,5) M,KG
    5 FORMAT(I2,I3)
      READ(5,1001)(NV(I),I=1,M)
 1001 FORMAT(25I3)
      WRITE(6,1003)(NV(I),I=1,M)
```

```
1003 FORMAT('OVARIABLES FOR THIS RUN ARE,'/,25I3/,28X,25I3)
 102 FORMAT(162(10A4))
1102 FORMAT(19X,4E14.7)
     EM=M
     EKG=KG
     EK=KG
     WRITE(6,6) M,KG
   6 FORMAT(13HOANALYSIS FOR I3,14H VARIABLES ANDI4,7H GROUPS)
     WRITE(6,9)
   9 FORMAT(1H0,25(5H-----))
     DO 7 J=1,M
     T(J)=0.0
     DO 7 K=1,M
     B(J,K)=0.0
   7 C(J,K)=0.0
     H1LOGS=0.0
     GA1S=0.0
     FA1S=0.0
     N=0
C
     DO 19 IG=1,KG
     READ(2,102)Y
     ISCN(IG)=Y(1)
     IWS(IG)=Y(2)
     NG=Y(3)
     DO 1124 I=1,4
1124 READ(2,102)(SDA(I,K),K=1,4)
     READ(2,102)(SM(K),K=1,4)
     ENG=NG
     N=N+NG
     WRITE(6,9)
     WRITE(6,10)IG,NG
  10 FORMAT(/1X,'GROUP',I3,'     NG=',I7)
     WRITE(6,1104)ISCN(IG),IWS(IG)
1104 FORMAT(/1X,'ERTS SCENE',I5,'  WATERSHED',I5)
```

```
      DO 11 J=1,M
      U(J)=SM(NV(J))
      DO 11 K=1,M
   11 A(J,K)=SDA(NV(J),NV(K))
      DO 12 J=1,M
      T(J)=T(J)+U(J)
      DO 12 K=1,M
   12 C(J,K)=C(J,K)+A(J,K)
      DO 13 J=1,M
      DO 13 K=1,M
      A(J,K)=A(J,K)-U(J) * U(K) / ENG
      B(J,K)=B(J,K)+A(J,K)
   13 A(J,K)=A(J,K) / (ENG-1.0)
      DO 14 J=1,M
      U(J)=U(J)/ENG
   14 W(J)=SQRT(A(J,J))
      WRITE(6,15)IG
   15 FORMAT(17H0MEANS FOR GROUP I4)
      WRITE(6,16) (     U(J),    J=1,M)
   16 FORMAT(1H0,10(3X,F7.2))
      WRITE(1,102)(U(J),J=1,M)
   30 FORMAT(4H ROWI3,3X, 5E14.7 / (10X,5E14.7))
      WRITE(6,17)
   17 FORMAT(21H0STANDARD DEVIATIONS  )
C
      WRITE(6,16)(W(J),J=1,M)
      DO 1004 J=1,M
 1004 WRITE(8,102)(A(J,K),K=J,M)
      CALL MATINV(A,M,DET)
      WRITE(6,18) DET
   18 FORMAT(26H0DISPERSION DETERMINANT =  E14.4)
      H1LOGS=H1LOGS+((ENG-1.0) *ALOG  (DET))
      FA1S=FA1S+(1.0/(ENG-1.0))
      GA1S=GA1S+(1.0/((ENG-1.0)**2))
   19 WRITE(6,9)
```

```
      REWIND 2
      REWIND 8
C
C
      EN=N
      DO 20 J=1,M
      DO 20 K=1,M
      A(J,K)=C(J,K)-T(J) * T(K)/EN
      D(J,K)=A(J,K)
   20 C(J,K)=B(J,K) / (EN-EKG)
      DO 21 J=1,M
      T(J)=T(J)/EN
   21 U(J)=SQRT (C(J,J))
      WRITE(6,22)
   22 FORMAT(23HOMEANS FOR TOTAL SAMPLE)
      WRITE(6,16)    (     T(J), J=1,M)
      KGT=KG + 1
      WRITE(1,102)(T(J),J=1,M)
      REWIND 1
      WRITE(6,23)
   23 FORMAT(35HOPOOLED-SAMPLES STANDARD DEVIATIONS    )
      WRITE(6,16)(U(J),J=1,M)
      WRITE(6,9)
      WRITE(6,38)
   38 FORMAT(9HOT MATRIX)
      DO 34 J=1,M
      WRITE(6,30)J,(A(J,K),K=J,M)
   34 WRITE(3,102)(A(J,K),K=J,M)
      REWIND 3
      WRITE(6,9)
      DO 35 J=1,M
      DO 35 K=1,M
   35 A(J,K)=A(J,K)-B(J,K)
C     A IS NOW THE A (AMONG-GROUPS SSCP) MATRIX.  B IS NOW THE W (WITHIN
C     GROUPS SSCP) MATRIX.  C IS NOW THE POOLED-GROUPS DISPERSION EST.
```

```
C
      WRITE(6,28)
   28 FORMAT(9H0A MATRIX)
      DO 29 J=1,M
   29 WRITE(6,30) J, (A(J,K), K=J,M)
      WRITE(6,9)
C
      WRITE(6,31)
   31 FORMAT(9H0W MATRIX)
      DO 32 J=1,M
      WRITE(6,30)J,(B(J,K),K=J,M)
   32 WRITE(4,102)(B(J,K),K=J,M)
      REWIND 4
      WRITE(6,9)
C
      CALL MATINV(C,M,DET)
C     DISPERSION MATRIX STORED ON DISK FILE.
      WRITE(6,1006)
 1006 FORMAT('0C MATRIX')
      DO 33 J=1,M
   33 WRITE(6,30)J,(C(J,K),K=J,M)
C
      WRITE(6,18) DET
      H1LOG=(EN-EK) * ALOG (DET)
      XMM=H1LOG-H1LOGS
      F1=.5 * (EK-1.0) * EM * (EM+1.0)
      A1A=(FA1S-(1.0/(EN-EK)))*((2.0 * (EM*EM))+(3.0 * EM)-1.0)
      A1=A1A/(6.0 * (EK - 1.0) * (EM+1.0))
      A2=(GA1S -(1.0 /(EN-EK)**2)) * ((EM-1.0) * (EM+2.0))
     C/(6.0 *(EK-1.0))
      DIF=A2-A1 * A1
      IF(DIF) 24,24,25
   24 F2=(F1+2.0)/(A1 * A1-A2)
      B1=F2 / (1.0 -A1+(2.0/F2))
      F=(F2 * XMM) /(F1 * (B1 - XMM))
```

```
      GO TO 45
   25 F2=(F1+2.0)/DIF
      B1=F1 / (1.0-A1 - (F1 / F2))
      F=XMM/B1
   45 NDF1=F1
      NDF2=F2
      WRITE(6,26) XMM,F
   26 FORMAT(47H0FOR TEST OF H1 (EQUALITY OF DISPERSIONS), M = F10.3,
     C10H AND F =  F10.3)
      WRITE(6,27) NDF1,NDF2
   27 FORMAT(15H0FOR F, NDF1 = I3, 12H AND NDF2 = I9)
      WRITE(6,9)
C
      N1=EKG-1.0
      N2=EN-EKG
      WRITE(6,9)
      WRITE(6,40)N1,N2
   40 FORMAT(34H0UNIVARIATE F-RATIOS, WITH NDF1 = I3,12H AND NDF2 = I6)
      WRITE(6,9)
      WRITE(6,41)
   41 FORMAT(71H0VARIABLE  AMONG MEAN SQ    WITHIN MEAN SQ     F-RATIO
     C      ETA SQUARE)
      DO 42 J=1,M
      ETASQ=A(J,J) / (A(J,J) + B(J,J))
      AMS=A(J,J) / (EKG-1.0)
      WMS=B(J,J) / (EN-EKG)
      F=AMS/WMS
   42 WRITE(6,43)J,AMS,WMS,F,ETASQ
   43 FORMAT(3X,I3,5X,F9.2,11X,F9.2,10X,F7.2,8X,F5.4)
      WRITE(6,9)
C
      CALL MATINV(B,M,DETW)
C     DETW IS DETERMINANT OF POOLED-SAMPLES DEVIATION SSCP MATRIX, W.
      CALL MATINV(D,M,DETT)
C     DETT IS DETERMINANT OF TOTAL SAMPLE DEVIATION SSCP MATRIX, T.
```

```
      XL=DETW/DETT
      YL=1.0-XL
      WRITE(6,46)XL,YL
   46 FORMAT('OWILKS LAMBDA = ',F7.4,'    GENERALIZED CORRELATION RATIO,
     1 ETA SQUARE = ',F5.4)
      IF(M-2)47,47,49
   47 IF(KG-3) 48,48,49
   48 YL=XL
      F1=2.0
      F2=EN-3.0
      GO TO 50
   49 SL=SQRT(((EM * EM) * ((EKG - 1.0)**2) - 4.0) / ((EM * EM) +
     2    ((EKG - 1.0)**2) - 5.0))
      YL=XL ** (1.0 / SL)
      PL=(EN-1.0)   - ((EM+EKG) / 2.0)
      QL=-((EM *(EKG -1.0))-2.0) / 4.0
      RL=(EM * (EKG-1.0)) / 2.0
      F1=2.0 * RL
      F2=(PL * SL)+(2.0 * QL)
   50 N1=F1
      N2=F2
      F=((1.0-YL) / YL) * (F2 / F1)
      WRITE(6,51)    F
   51 FORMAT(45HOF-RATIO FOR H2, OVERALL DISCRIMINATION, =   F9.2)
      WRITE(6,52)  N1,N2
   52 FORMAT('ONDF1 = ',I3,' AND NDF2 = ',I9)
      WRITE(6,9)
      KC=0
      CALL DISCMX
      GO TO 1
   53 STOP
      END
```

MATINV

```
      SUBROUTINE MATINV(A,M,DET)
      DIMENSION A(20,20),IPVT(100),PVT(100),IND(100,2)
      DET=1.
      DO 1 J=1,M
    1 IPVT(J)=0
      DO 10 I=1,M
      AMAX=0.0
      DO 5 J=1,M
      IF(IPVT(J)-1)2,5,2
    2 DO 5 K=1,M
      IF(IPVT(K)-1)3,5,20
    3 IF(ABS(AMAX)-ABS(A(J,K)))4,5,5
    4 IROW=J
      ICOL=K
      AMAX=A(J,K)
    5 CONTINUE
      IPVT(ICOL)=IPVT(ICOL)+1
      IF(IROW-ICOL)6,8,6
    6 DET=-DET
      DO 7 L=1,M
      SWAP=A(IROW,L)
      A(IROW,L)=A(ICOL,L)
    7 A(ICOL,L)=SWAP
    8 IND(I,1)=IROW
      IND(I,2)=ICOL
      PVT(I)=A(ICOL,ICOL)
      DET=DET*PVT(I)
      A(ICOL,ICOL)=1.
      DO 9 L=1,M
    9 A(ICOL,L)=A(ICOL,L)/PVT(I)
      DO 10 L1=1,M
      IF(L1-ICOL)11,10,11
   11 SWAP=A(L1,ICOL)
      A(L1,ICOL)=0.0
```

```
   DO 12 L=1,M
12 A(L1,L)=A(L1,L)-A(ICOL,L)*SWAP
10 CONTINUE
   DO 20 I=1,M
   L=M+1-I
   IF(IND(L,1)-IND(L,2))13,20,13
13 IROW=IND(L,1)
   ICOL=IND(L,2)
   DO 20 K=1,M
   SWAP=A(K,IROW)
   A(K,IROW)=A(K,ICOL)
   A(K,ICOL)=SWAP
20 CONTINUE
   RETURN
   END
```

SPLIT

```
       ENT       SPLIT
SPLIT  DC        *-*
       STX    1  XR1+1
       STX    2  XR2+1
       STX    3  XR3+1
       LDX   I1  SPLIT
       LD     1  0
       STO       ADD1+1
       LD     1  1
       STO       ADD2+1
       LD    I1  2
       SLA       1
       STO   I1  2
       STO       COUNT+1
       MDX    1  3
       STX    1  BACK+1
ADD1   LDX   L1  *-*
ADD2   LDX   L2  *-*
COUNT  LDX   L3  *-*
LOOP   SLT       16
       LD     1  0
       RTE       16
       SLT       8
       STO    2  0
       MDX    2  -1
       SLA       16
       SLT       8
       STO    2  0
       MDX    1  -1
       MDX    2  -1
       MDX    3  -2
       MDX       LOOP
XR1    LDX   L1  *-*
XR2    LDX   L2  *-*
```

SPLIT CONTINUED

```
XRO     LDX   L3  *-*
BACK    BSC   L   *-*
        END
```

HALF

```
         ENT        HALF
HALF     DC         *-*
         STX    1   XR1+1
         STX    2   XR2+1
         STX    3   XR3+1
         LDX    I1  HALF
         LD     1   0
         STO        ADD1+1
         LD     1   1
         STO        ADD2+1
         LD     I1  2
         STO        COUNT+1
         SLA        1
         STO    I1  2
         MDX    1   3
         STX    1   BACK+1
ADD1     LDX    L1  *-*
ADD2     LDX    L2  *-*
COUNT    LDX    L3  *-*
LOOP     LD     1   0
         SRT        8
         STO    2   0
         XCH
         SRT        8
         STO    2   -1
         MDX    1   -1
         MDX    2   -2
         MDX    3   -1
         MDX        LOOP
XR1      LDX    L1  *-*
XR2      LDX    L2  *-*
XR3      LDX    L3  *-*
BACK     BSC    L   *-*
         END
```